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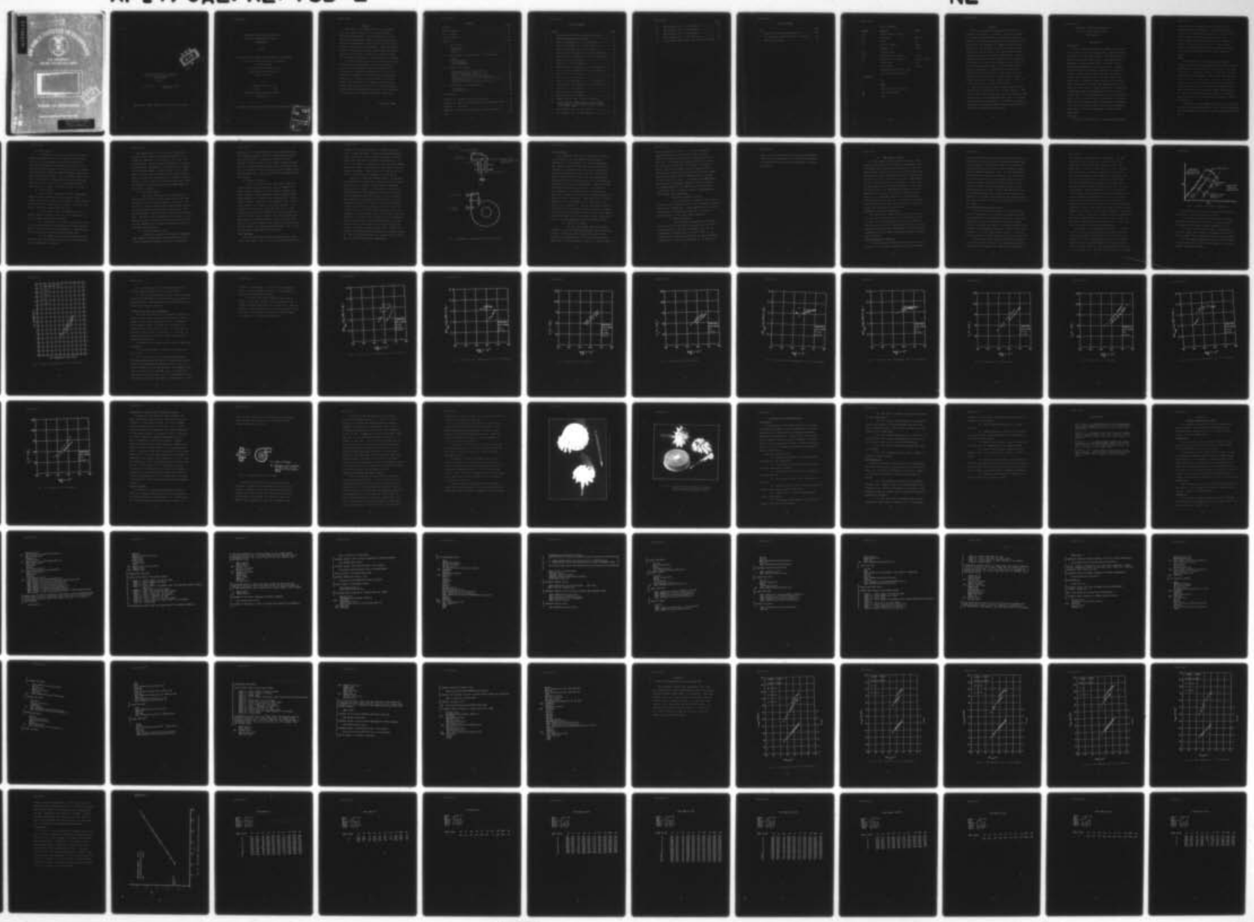

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PARAMETRIC PERFORMANCE EVALUATION OF A JET ENGINE DERIVED FROM A TURBOCHARGER

THESIS

GAE/AE/76D-2

Richard B. Brown
Major USAF

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PARAMETRIC PERFORMANCE EVALUATION OF A JET ENGINE DERIVED FROM A TURBOCHARGER

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

By

Richard B. Brown, B.S.
Major USAF
Graduate Aeronautical Engineering

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Approved for public release; distribution unlimited.

Preface

This thesis is a follow-on work to a conceptual study of a small, low-cost, jet engine based on a production turbocharger. The study employed a much improved instrumentation system to obtain steady state performance parameters to determine the optimum thrust producing configuration, unaugmented. Experimental performance exceeded the original maximum predicted thrust levels by a significant margin which greatly enhanced the turbocharger derived jet engine feasability concept.

I wish to express thanks to the following for their contributions and assistance: Dr. William Elrod, my advisor; Drs. Andrew Shine and Harold Wright of the Aeromechanical Engineering department of the Air Force Institute of Technology for their advice and technical assistance; Mr. Shortt and the personnel of the AFIT machine shop for their direct support of the project hardware design and modification; Dr. Wilhelm Ericksen of the Mathematics department of the Air Force Institute of Technology for his expert programming assistance.

Richard B. Brown

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Symbol	Quantity	Units
A/R	Turbine housing number	-
F/F	Fuel flow	lb_m/hr
F_n	Thrust	lb_f
$\dot{m}$	Rate of airflow	lb_m/hr
P	Pressure	lb/in^2
P_{rc}	Pressure ratio	-
RPM	Revolutions per minute	1/min
SFC	Specific fuel consumption	$(lb_m/hr)/(lb_f)$
T	Temperature	deg
W	Rate of flow	lb_m/hr
	Temperature correction (T/T_o)	-
	Pressure correction (P/P_o)	-

Subscripts

a	Air
f	Fuel Force
o	Standard sea level values
∞	Free stream values
m	mass

Abstract

Previous conceptual studies have shown that it is feasible to construct a low-thrust, jet engine, based on a production turbocharger at relatively low cost. A parametric evaluation was performed on a turbojet engine derived from an AiResearch 1.5 lb_m/sec airflow turbocharger unit to determine its static performance characteristics and the maximum attainable thrust without augmentation or major component modification. The performance of various turbine housing/nozzle combinations was measured in steady state operation using a much improved instrumentation system, together with various system improvements. Parameters were measured on a common time base and plotted to depict the total performance of the unit over its usable range. Maximum thrust obtained was 97 lb_f, exceeding the initially predicted theoretical value of 67 lb_f by 45%.

Data was reduced to coded 3 digit numbers for programming and plotting using the CDC 6600 computer. The results were machine plots depicting the performance characteristics of the unaugmented engine for use in further studies including augmentation. In addition, computer performance programs for coded raw data were written for future data reduction and analysis.

PARAMETRIC PERFORMANCE EVALUATION OF A JET ENGINE DERIVED FROM A TURBOCHARGER

I. Introduction

Background

The Air Force Aero Propulsion Laboratory has identified a need for and is studying small, low-cost propulsion devices for RPV applications. The present work is part of an ongoing study at AFIT to develop such an expendable, jet engine comprised of a low-cost, high production turbocharger as the primary unit, together with off-the-shelf and locally fabricated components. Present turbojet engines cost much more than such an engine, and, generally, are in a higher thrust range. While small, low-thrust engines do exist and are being used, such engines typically cost approximately $73 per pound of thrust while an engine derived from a production turbocharger would cost approximately $22 per pound of thrust (Ref. 1). The possibility of a large cost savings exists if this low-cost engine's performance is adequate. While prior work was primarily a conceptual and feasability study, the present efforts are aimed at developing performance to the level necessary for small vehicle application.

Objective

The primary objective was to develop the performance

envelope for the unaugmented engine, based on the AiResearch T18A-E turbocharger, and to determine the optimum thrust producing configuration. This consisted of the engine performance operating lines, RPM curves, thrust curves, and specific fuel consumption curves. Secondary objectives were to make various system improvements and develop a computer data reduction and plotting program for the above mentioned curves.

Scope

The experimental investigation was limited to varying two configuration parameters: the turbine housing, identified by an A/R number (see section III), and conical nozzles of fixed exit diameter, which were locally fabricated in the AFIT shop. The turbine housings used were a 1.32 A/R, 1.5 A/R, and a 1.7 A/R. The nozzles ranged in size from 2 inches to 3¼ inches exit diameter in increments of 1/8 inch. Other system changes were made for the purpose of improving engine performance or to improve the test operation as a whole. No attempt was made to achieve a configuration suitable for vehicle installation.

The analytic investigation was limited to an analysis of engine performance parameters, since the primary purpose was the gathering and reduction of hard engine performance data.

II. Test Apparatus, Modifications, and Procedures

Considerable work has been done to improve the instrumentation and control of the test stand facility (see Fisher, Ref. 3) including complete operation and control of the engine from a safe position in the control room and continuous 10 parameter monitoring and recording (with 18 channel capability). This together with several engine improvements provided a reliable and accurate facility to record experimental performance data. This section briefly describes the engine tested, the modifications to the engine and engine support equipment, and the general test procedure which was followed, including recommendations for follow-on testing.

Engine

The engine tested consisted of an AiResearch T18A-E turbocharger as the basic unit together with a modified combustor from a MA1A ground power unit, a fixed diameter conical nozzle, a standard design inlet bellmouth with a 4.057 inch throat diameter, and the associated oil, air, fuel, and electrical systems (see Kent and Greene, Ref. 1 and 2 for a detailed discussion of engine and combustor development). This unit provides a nominal 1.5 lb_m/sec airflow and is the larger of the two units developed by Kent and Greene.

Modifications

One of the main objectives, besides obtaining accurate,

repeatable, performance data over the useful range of operation of the unaugmented engine was to improve the test stand operation as a whole in order to facilitate follow-on testing. It was also desired to make the engine compatible with a newer instrumentation and control system, and to improve ease of operation and facilitate data gathering. Additionally, since testing was to be done at maximum performance, safety considerations became increasingly important. With these objectives in mind, the following modifications were made:

(1) Oil System

Several early potential problems were encountered with the oil supply system due to oil backing into the bearing housing and leaking through the seals. This could not only result in faulty operation but constituted an unnecessary fire hazard. Therefore, the problem was corrected by providing a direct gravity flow return line which terminated above the reservoir oil level. Also, all mechanical restrictions were removed so there was no possibility of oil backing up the return line. Pressure was controlled by a regulating valve in parallel with the constant volume oil pump and maintained at 30 psi minimum with normal pressure maintained at 40 to 50 psi to keep from over-pressurizing the seals. It is recommended that the 30 psi minimum be retained since experience has shown that the possibility of bearing failure exists with oil pressure below this value.

(2) Fuel System

In addition to the previous fuel system which supplied pressurized fuel to an atomizer spray nozzle, two electrically operated fuel shut-off valves were installed for normal and emergency fuel shut-off. To provide for flow metering to the spray nozzle, a console mounted throttle switch was installed which controlled a motor driven needle valve. Also, a portable abort switch which controlled the emergency fuel shut-off valve was installed in the test cell as a safety feature when it was necessary to inspect the engine during a test run.

(3) Airflow System

This system is comprised of those components, other than the turbocharger, which supply, direct, or control the airflow direction and pressure. This includes the high pressure airstart line, nozzles, and inlet bellmouth. The major changes made here were:

(a) the addition of a bellmouth fillet to provide smooth airflow to the face of the compressor to aid in accurate mass flow measurement.

(b) the addition of a brass inner sleeve and an outer aluminum shroud to the compressor discharge hose to protect the hose from the high temperature compressor discharge air and from the hot turbine housing, and

(c) the addition of a console mounted airflow shut-off switch to provide control for starting and motoring the engine when necessary.

The nozzles used in the tests were fabricated in the AFIT machine shop in sizes ranging from 2 to $3\frac{1}{4}$ inches exit diameter, in increments of 1/8 inch. The fixed geometry, conical design was chosen for simplicity of fabrication, reliability, and especially for repeatability of performance. Nozzles larger than $3\frac{1}{4}$ inches were not tested since they would produce only marginal thrust increase with great increase in specific fuel consumption. Also, larger size nozzles produce hard starts and instability as the nozzle diameter approaches the turbine exit diameter.

(4) Electrical System

The major changes were the installation of electrically operated console mounted control switches which were used to start and operate the engine. The 10,000 volt, spark ignition system was retained with the minor modification of providing a single cable, self-contained ground, which provided a more positive electric arc. The spark igniter occasionally failed due to overheated insulation, which in turn caused a short circuit, but was otherwise very reliable and provided excellent starting characteristics.

(5) Turbine Inspection Hole

Although the possibility existed of operating with damaged but functional turbine blades with a resulting degraded performance and lack of uniformity

between runs, it was prohibitive to tear down the engine for inspection between each run to determine the condition of the blades. To solve this problem, a small diameter hole was drilled in the turbine housing and tapped for an inspection plug which could be removed between runs to determine if there had been any heat damage to the turbine blade tips. This assured uniform performance from the turbine.

(6) Gaskets and Seals

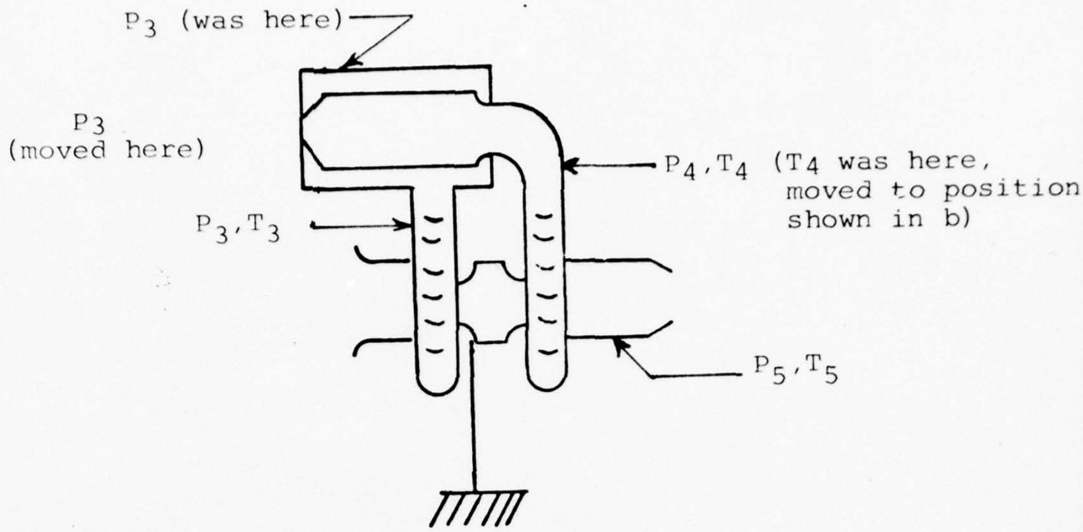
Since in a small engine, even minor losses can be significant, every attempt was made to tighten the system against leakage. For this reason, gaskets, and, where necessary, high temperature sealing compound were placed between the combustor dome and combustor, igniter plug and socket, spray nozzle and combustor dome, and the joint between the combustor and turbine housing. It is worthy to note for future work that the use of a high temperature, anti-seize compound was found most useful to aid in removing clamps, nozzles, and fittings which had been heated to red temperatures. Also, to insure tight seals, all joining surfaces were brushed and treated with sealant anytime that parts were disassembled, even if gaskets and seals appeared to be serviceable.

Test Equipment

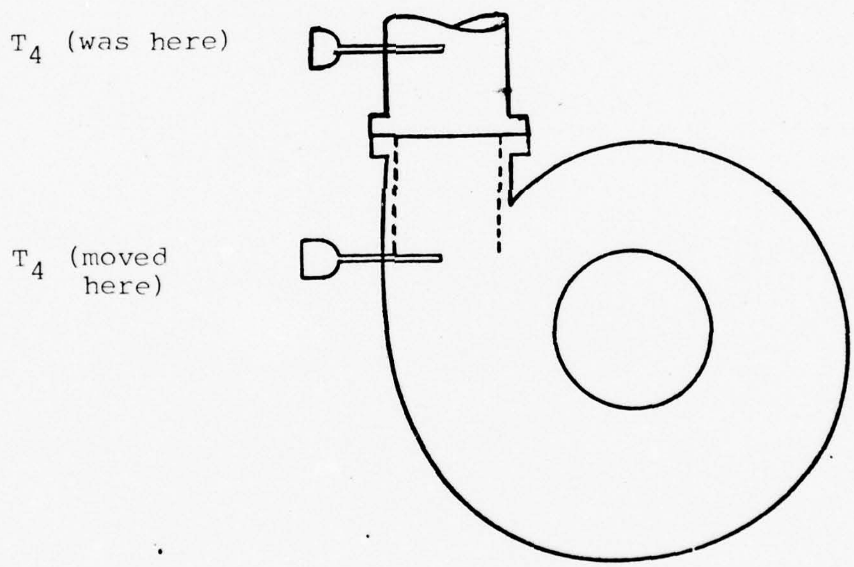
The instrumentation and control system was a major effort (see Fisher, Ref. 3, for a detailed discussion) and

allowed for gathering continuous, steady state data with a common time base. The primary recording device was an 18 channel strip recorder using photo sensitive paper which was used to record the parameters P_3, P_4, P_5, T_3, T_4, and T_5, in addition to the fuel flow, thrust, RPM, and airflow. The subscripts correspond to the compressor discharge, turbine inlet, and turbine exit stations, respectively, for pressure and temperature.

Figure 1(a) shows the changes made to the pressure and temperature sensing system during initial instrumentation tests. To obtain a more accurate compressor pressure ratio reading, it was decided to reposition the P_3 probe from the combustor outer liner to the end of the compressor housing diffuser. Also, two probes were used with a y-connection instead of one to obtain an average pressure. In addition, the T_4 thermocouple located at the position indicated in Fig. 1(a) was directly exposed to the high temperature flame from the combustor, especially when the 1.32 A/R housing was used. Therefore, to prevent loss of probes due to overtemperature and obtain a more accurate indication of gas temperature entering the turbine, the T_4 thermocouple was moved to the position shown in Fig. 1(b). Turbine exit pressure and temperature were measured as shown by P_5 and T_5. The T_5 reading was used as a console control instrument to indicate exhaust gas temperature.



(a)



(b)

Fig. 1, Temperature and Pressure Sensor Locations

Test Procedures

Test procedures called for determining the maximum performance for each possible housing/nozzle combination. To accomplish this, several procedures were adopted, both to insure that the data would be as accurate as possible and that the tests be completed as safely as possible. Early tests were for the purpose of determining the start, run, and shutdown sequences with the new control system and to calibrate the instrumentation and recording systems. This was accomplished on the first six test runs, I-1 through I-6 (see Appendix C for explanation of run designation). Data taken through run I-6 was not considered usable for presentation in the results. Data taken from test runs beginning with I-7 through I-29 are presented in the results and in Appendix C. Typical tests began with the calibration of the pressure sensing transducers, temperature sensing thermocouples, and the thrust strain guage. This was followed by an idle inspection run, normal test profile, maximum performance test, or endurance test.

(1) Normal Test Profile

All test runs except those for maximum endurance, idle, and maximum performance tests consisted of start, stabilized idle, stepped increases in fuel pressure, and approximately 10 seconds of steady-state operation to allow readings to stabilize, continued up to

maximum temperature (2000 ^{o}F). This was followed by stepped decreases in fuel pressure down to idle to observe for hysteresis and check repeatability of the test data. The engine was allowed to run for 2 minutes at idle power to cool prior to shutdown. The procedure of motoring the engine with air pressure was discontinued since there was less likelihood of heat damage with the two minute idle and shutdown than by blowing air over the red hot metal. A recording of temperatures following an idle shutdown showed a slight increase in gas temperature with all temperatures leveling off at a safe value, with a maximum increase of approximately 150 ^{o}F above idle temperatures.

(2) Maximum Performance Testing

The test profile to determine maximum performance limits consisted of idle start, advance to 2000 ^{o}F turbine inlet temperature, stable operation for 5 minutes followed by idle cooling and shutdown. This profile demonstrated a 5 minute full power capability.

(3) Endurance Testing

It was desired to demonstrate a minimum mission time of 30 minutes at reduced thrust (1800 ^{o}F), and although this test was not completed, it was concluded that the engine has a 30 minute capability at reduced thrust, based on accumulated run time at maximum temperature. Since cyclic operation is, in nearly all

cases, a more severe stress than continuous operation, 30 minutes of accumulated time without failure should be indicative of mission time greater than 30 minutes continuous.

III. Experimental Results

The experimental results obtained were most satisfactory in that they not only showed a performance level considerably above that originally predicted, but gave rather uniform results over the entire performance range attainable with the turbocharger/component combinations available for this engine with very little experimental scatter. Some data had to be discarded as invalid and all parameters were not always measurable. It was soon discovered that in an experimental situation, with new equipment and procedures, the failure rates are very high and it is extremely difficult to keep everything working perfectly all the time. Nevertheless, the data taken was considered valid and sufficiently complete to display the performance of the engine.

Discussion of Overall Performance

The turbocharger tested produced an engine in the 100 lb_f thrust class operating at 74,000 RPM with a SFC of 1.74. It is a temperature limited device (2000 ^oF) which, together with the turbine housing/nozzle, set the maximum thrust attainable, unaugmented. No further thrust advantage is likely without major modification or configuration change.

Thrust Performance (General)

The maximum thrust achieved (corrected) was 97 lb_f with the 1.5 A/R turbine housing and the 3¼ inch nozzle.

The earlier thrust predictions of 67 lb_f by Kent (Ref. 1) were based on a design point thermodynamic Brayton cycle analysis program called Carpet (Ref. 4) which predicts the performance of an engine, given the maximum temperature, compressor pressure ratio, and the appropriate efficiencies of the engine components. While the analysis by Kent was correct, the assumed operating line of maximum adiabatic compressor efficiency used to make initial estimates of the performance turned out to be significantly to the left of the actual operating lines, as measured by experiment. Additionally, mass flows in excess of 1.5 lb_m per second were not anticipated, while the maximum actually achieved experimentally was 1.63 lb_m per second.

Engine Performance Operating Lines

The engine operating lines for the various configurations correspond to the pressure required by the system downstream of the compressor and represent the flow resistance of a given assembly of combustion chamber, turbine, tailpipe, and nozzle. The curves indicate lines on which the compressor operates in a stable fashion when installed in a given fixed geometry engine. All values are corrected to standard values of 14.7 psi and 518.7 ^{O}R.

Since the data was recorded at arbitrary RPM points, it was necessary to cross plot P_{rc} and W_a versus RPM to obtain lines of constant RPM. These lines correspond to

the pressure available from the compressor. All RPM operating lines terminate at a surge or stall limit (see Fig. 2) the sum of which forms the surge line which puts a limit on stable operation. Since, however, the testing was not done at constant RPM as is often the case in compressor development, the surge line could not be determined directly. Instead, the performance envelope boundaries were determined by varying system pressure demand by changing nozzles until stall or surge was reached. Thus the operating line of the smallest nozzle capable of sustained, steady-state operation with a given turbine housing would lie just to the right of the surge line and the operating line of the largest nozzle would lie just to the left of the outer instability boundary. Larger nozzles would not supply enough pressure demand on the system to allow stable operation. The dotted line in Figure 2 represents an outer stability boundary for the case of operation with no nozzle. Since it was not possible to obtain sustained burning with no nozzle, such lines could not be determined experimentally.

The operating lines presented in Figs. 3, 4, and 5 are for nozzles which provided smooth, stable operation with a given turbine housing over its entire range of operation. Thus a 2 inch nozzle would not allow stable operation with any turbine housing, and nozzles smaller than 2 ½ inches would not allow stable operation with the 1.7 A/R housing, etc., and thus this data was not recorded.

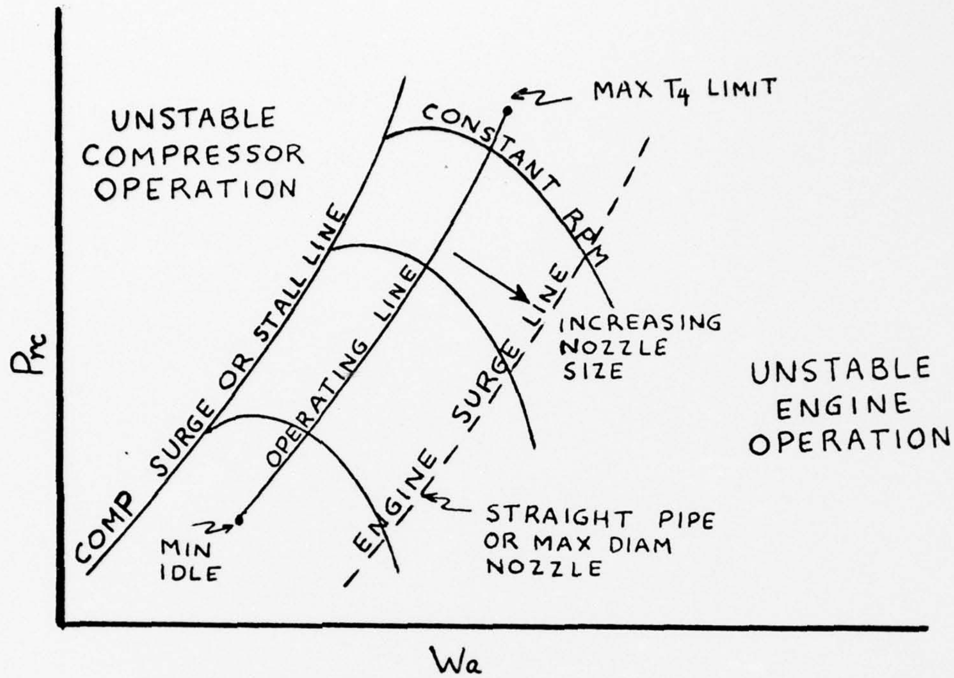


Fig. 2 Typical Compressor Performance

An analysis of the engine performance operating line data leads to several significant results:

(1) All data lies within a performance envelope bounded by a compressor surge limit, a maximum turbine temperature limit, and an engine instability limit.

(2) For a given turbine housing, and fixed P_{rc}, increasing nozzle size results in increased airflow until engine instability is encountered with too large a nozzle.

(3) The maximum temperature limit (2000 ^{o}F) occurs at nearly the same P_{rc} for any size nozzle, for a given turbine housing A/R number.

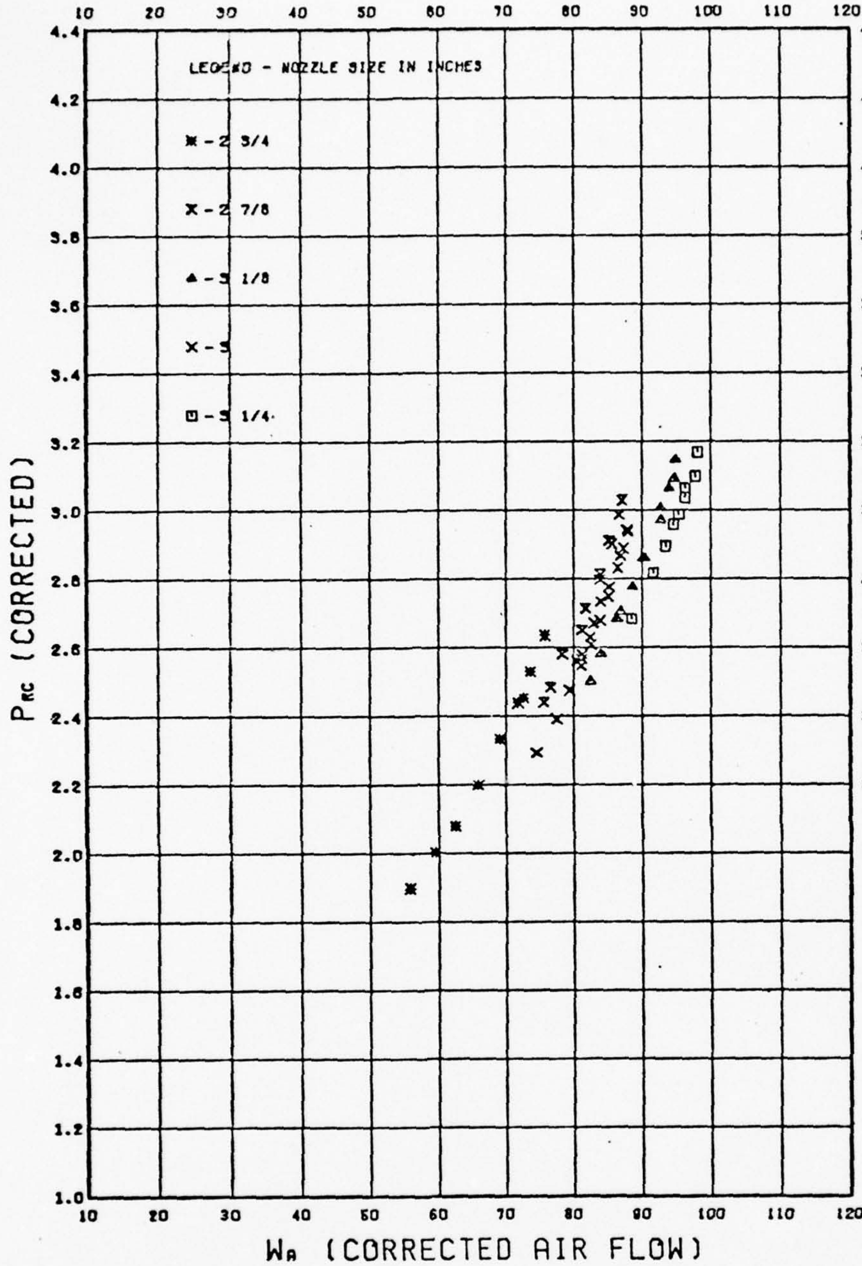


Fig. 3 Engine Performance for 1.32 A/R Housing

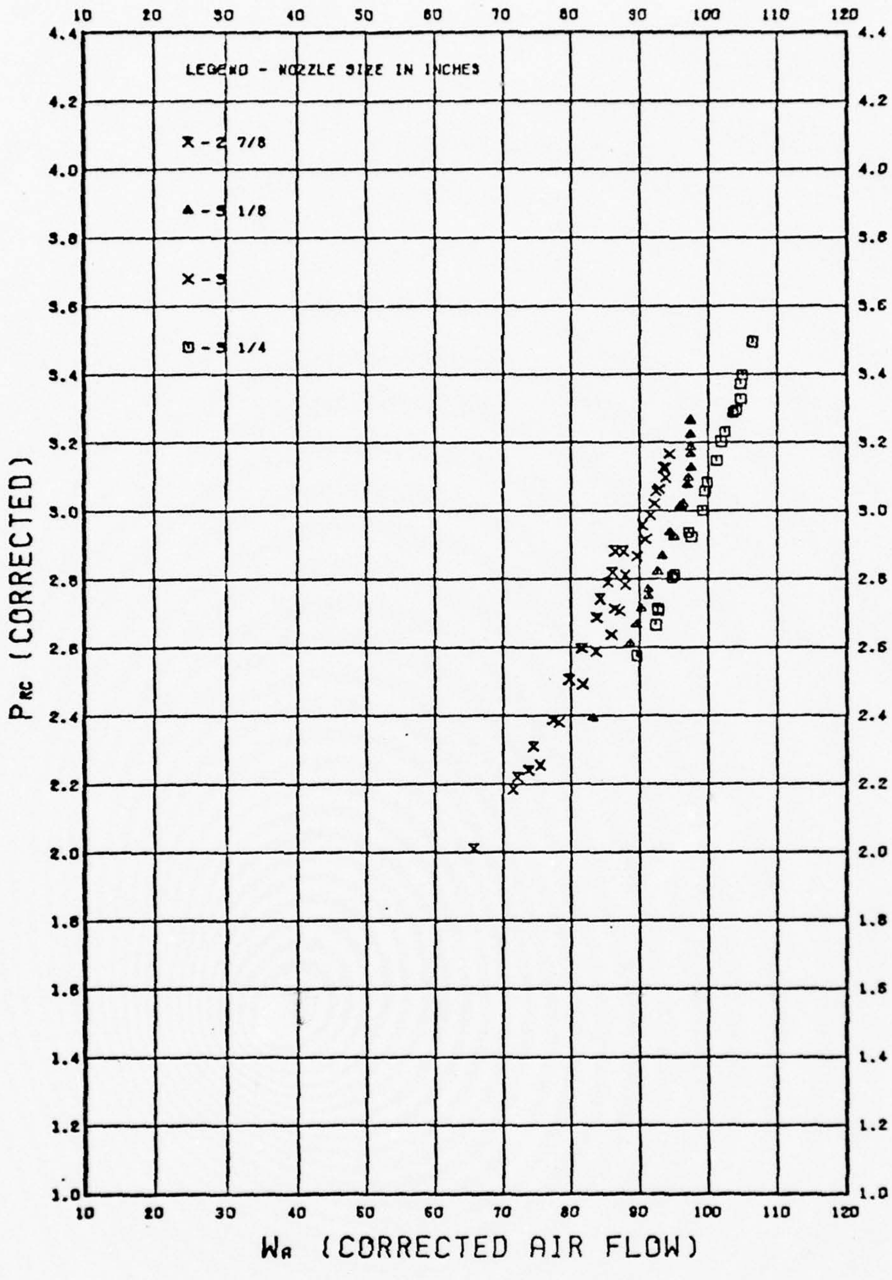


Fig. 4 Engine Performance for 1.5 A/R Housing

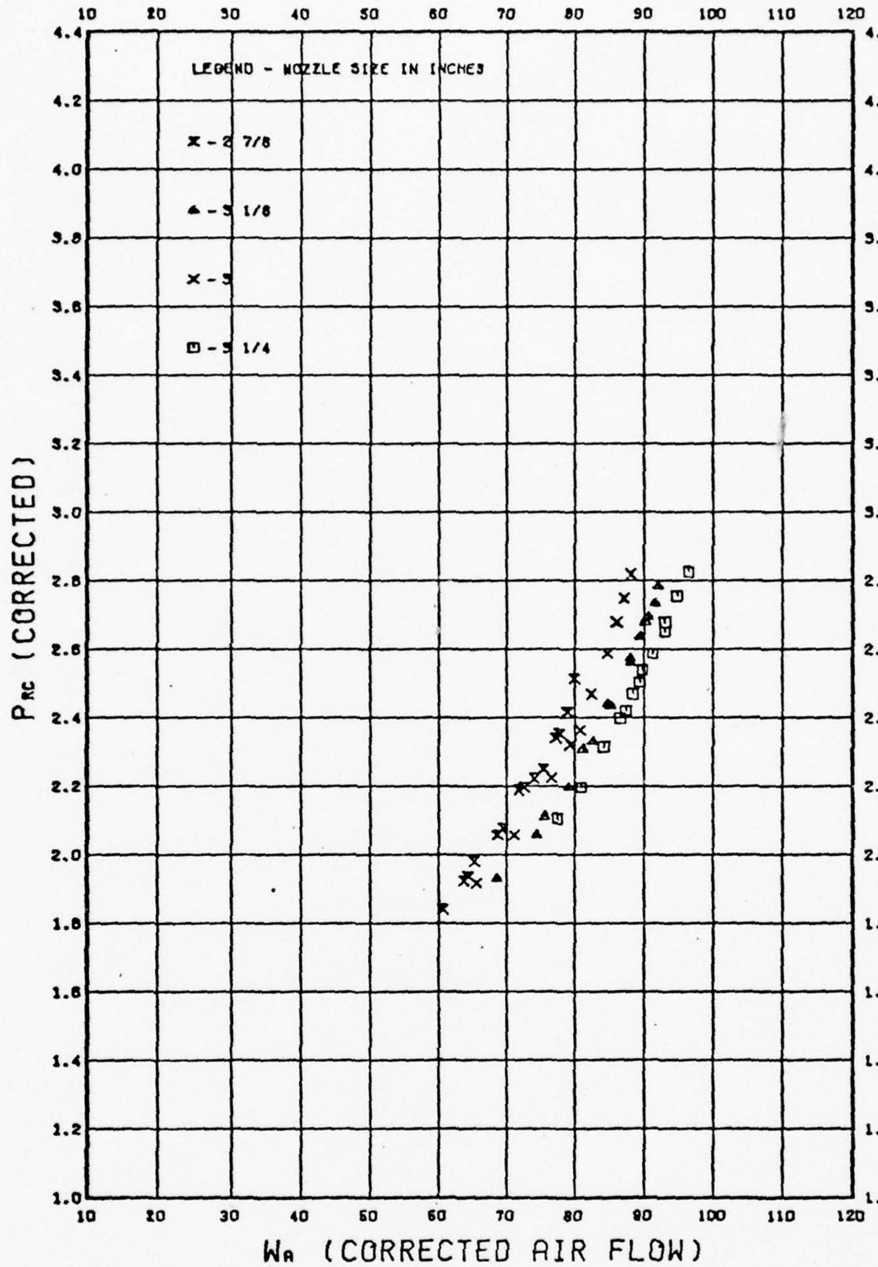


Fig. 5 Engine Performance for 1.7 A/R Housing

(4) A maximum P_{rc} of 3.5 was achieved with the 1.5 A/R turbine housing and the 3 ¼ inch nozzle.

(5) For all configurations tested, the data showed a distinct tendency for the slope of the P_{rc}/W_a curve to become infinite. This indicates the points at which the maximum mass flow was achieved.

Thrust and Specific Fuel Consumption

The thrust and specific fuel consumption (SFC) performance of the three turbine housings with the various nozzle configurations are shown in Figs. 6 through 17 plotted against RPM. All values are corrected to a standard value of 14.7 psi and 518.7 ^{O}R. With the exception of some of the 1.32 A/R and 1.7 A/R curves, the data shows expected values, the thrust curves showing uniform good results.

An analysis of the thrust and SFC results showed the following:

(1) Best performance in thrust and SFC was with the 1.5 A/R.

(2) The 1.32 A/R and 1.7 A/R housings exhibited off-design performance with either a significant loss of thrust at the same RPM, as compared to the 1.5 A/R or a large increase in SFC at the same RPM. For example, with the 3 inch nozzle at 60,000 RPM, the 1.5 A/R produced approximately 65 lb_f thrust; the 1.32 A/R produced no more than 60 lb_f thrust with any nozzle, and while the 1.7 A/R

produced 72 lb_f thrust, it did so with an increase in SFC of .22 (an increase in SFC of .1 is considered a significant percentage increase).

(3) Several SFC curves exhibited atyptical behavior in that they failed to curve upwards with decreasing RPM below the point of 'minimum' SFC. This was believed to be due primarily to the non-linearity of the flow meter and frequency converter at low flow rates. (See Appendix C for further discussion.)

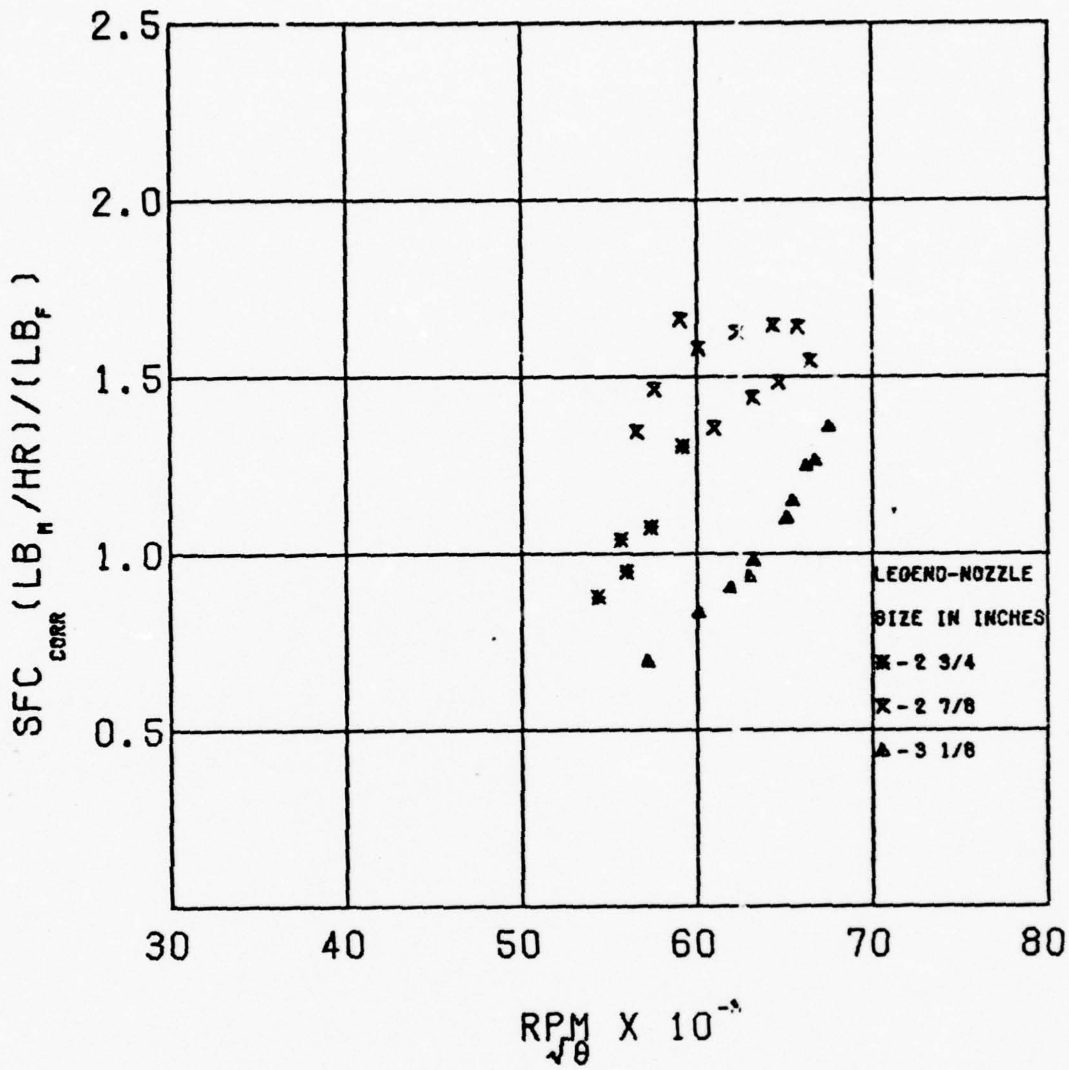


Fig. 6 Specific Fuel Consumption for 1.32 A/R Housing

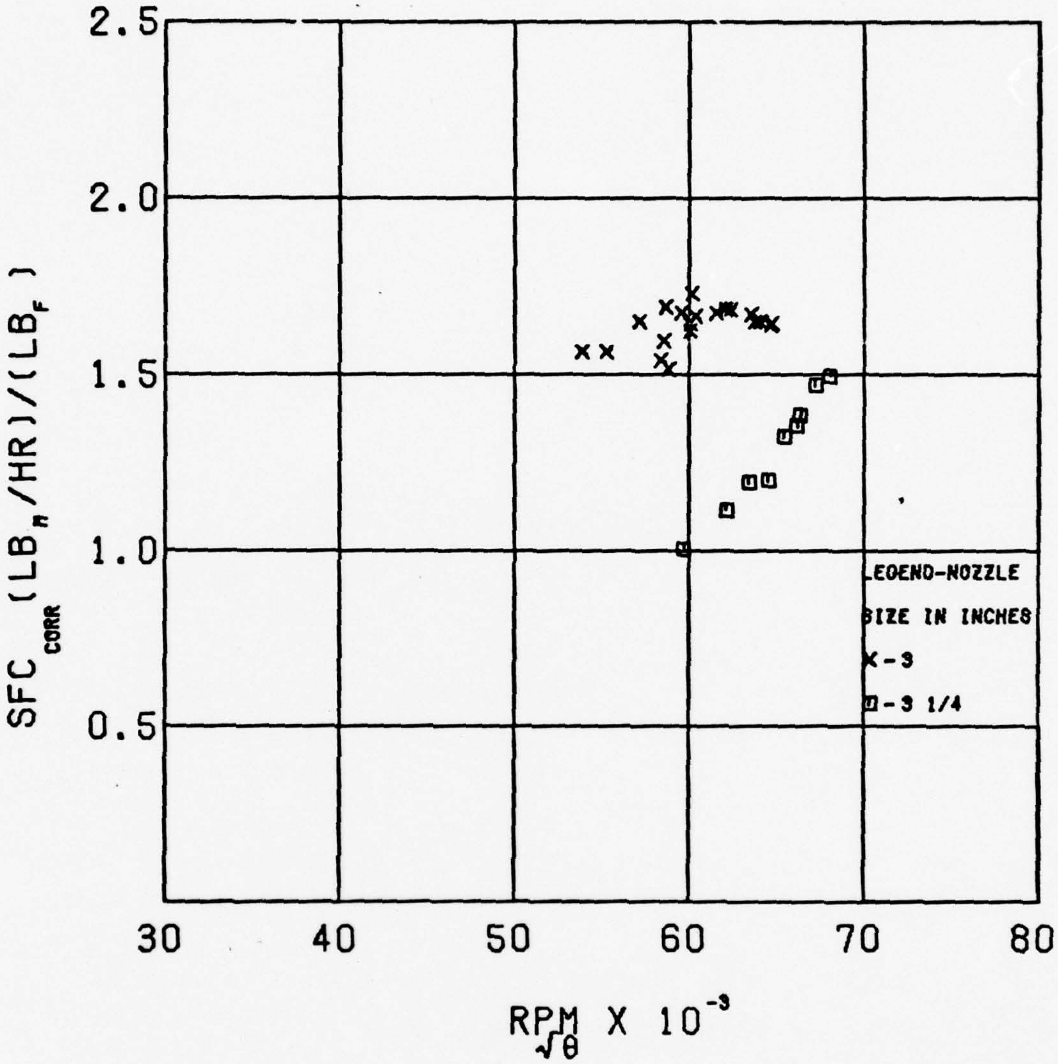


Fig. 7 Specific Fuel Consumption for 1.32 A/R Housing

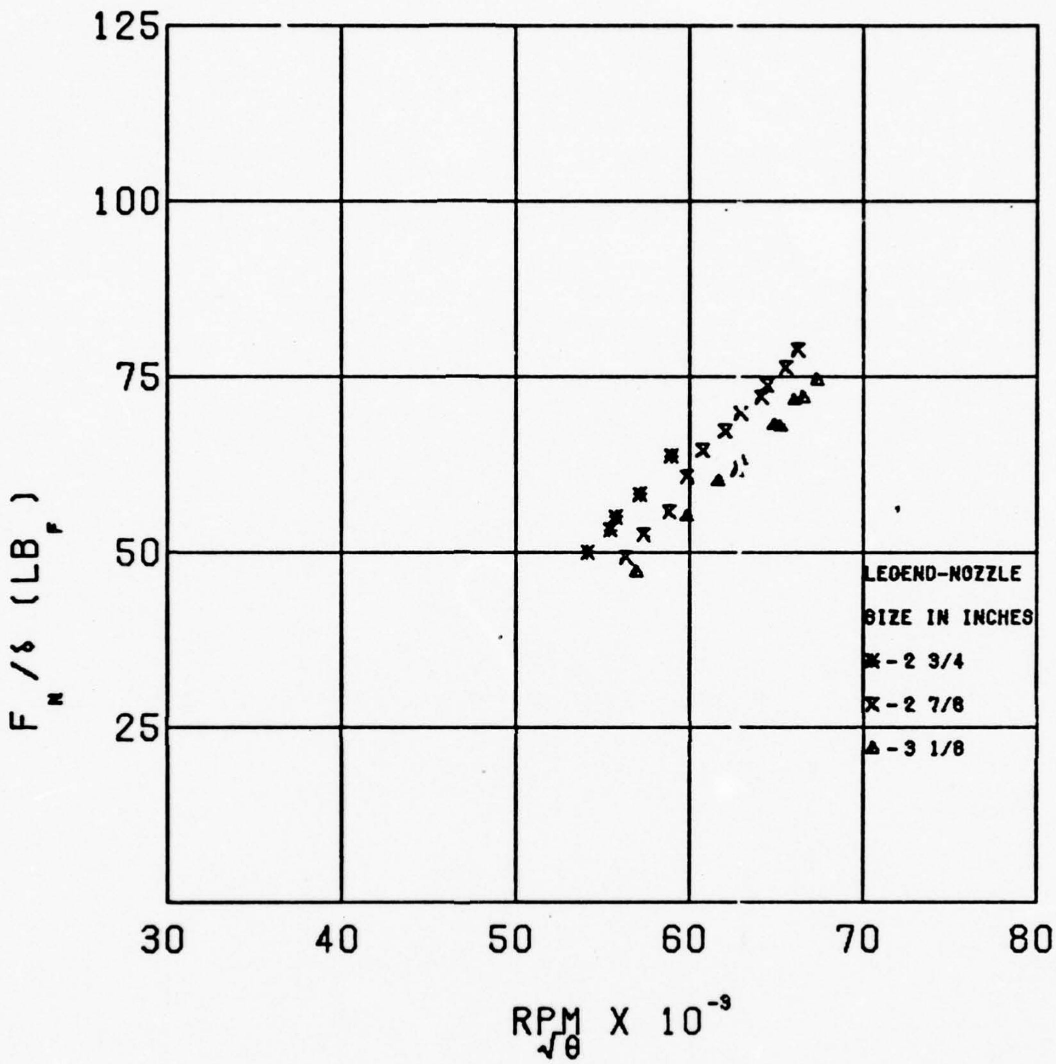


Fig. 8 Thrust for 1.32 A/R Housing

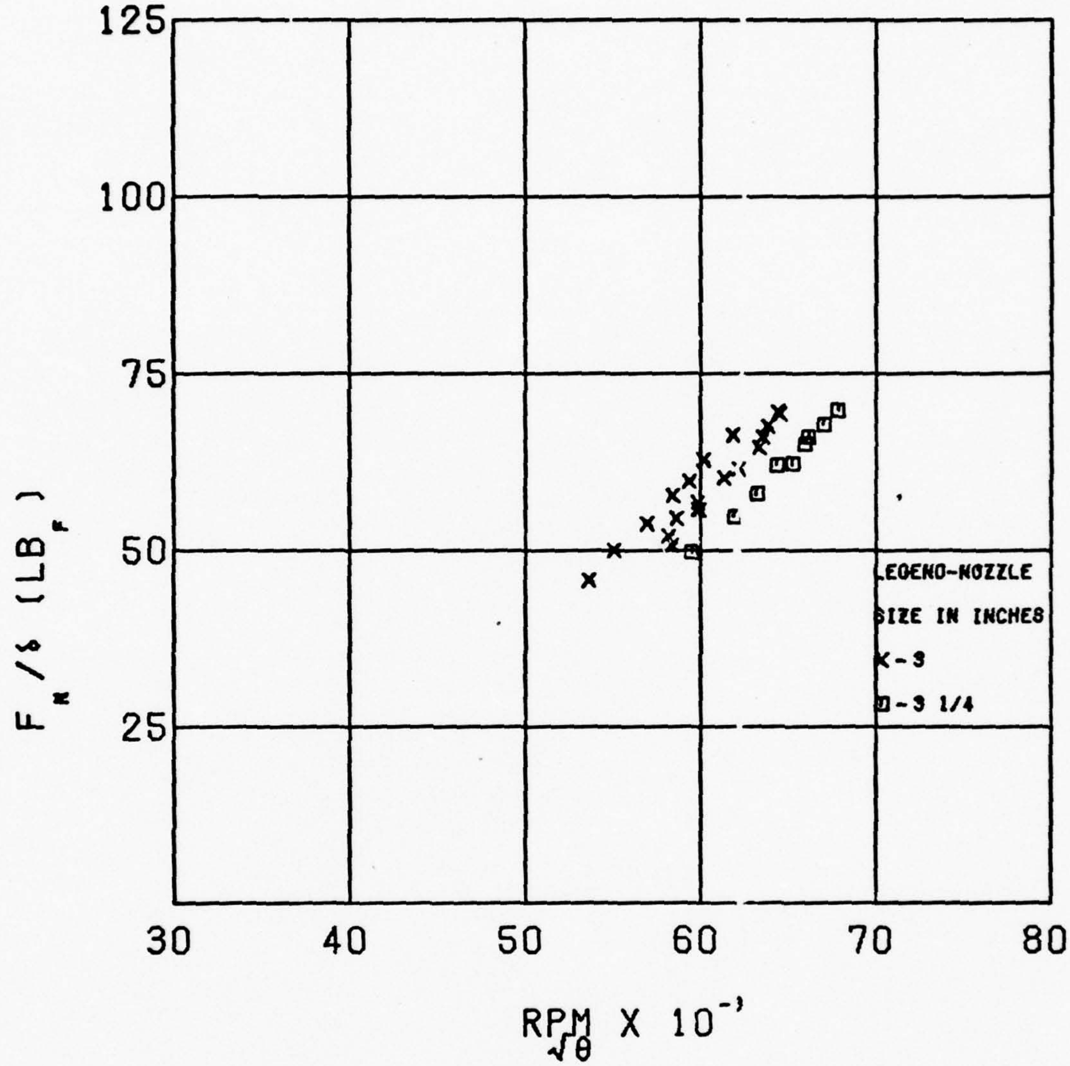


Fig. 9 Thrust for 1.32 A/R Housing

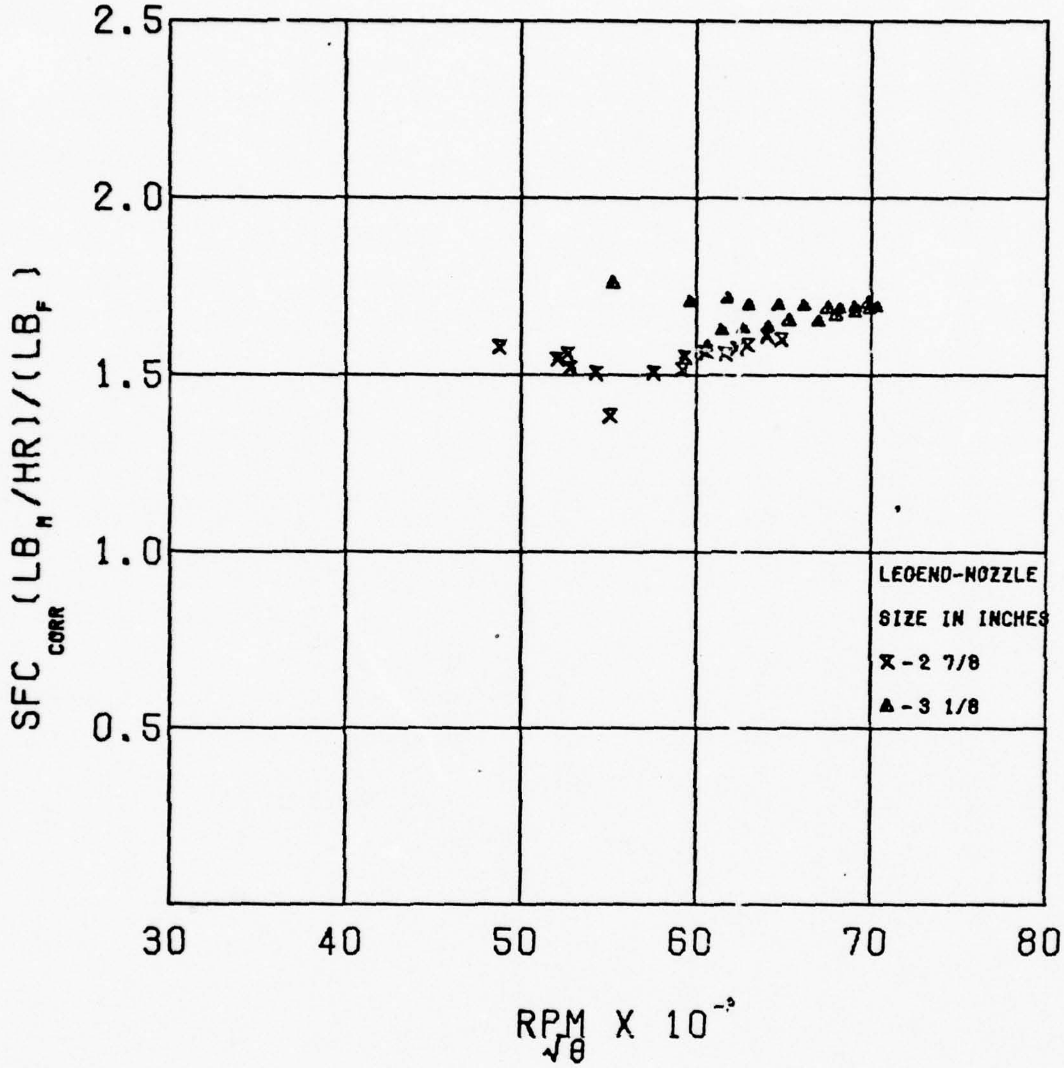


Fig. 10 Specific Fuel Consumption for 1.5 A/R Housing

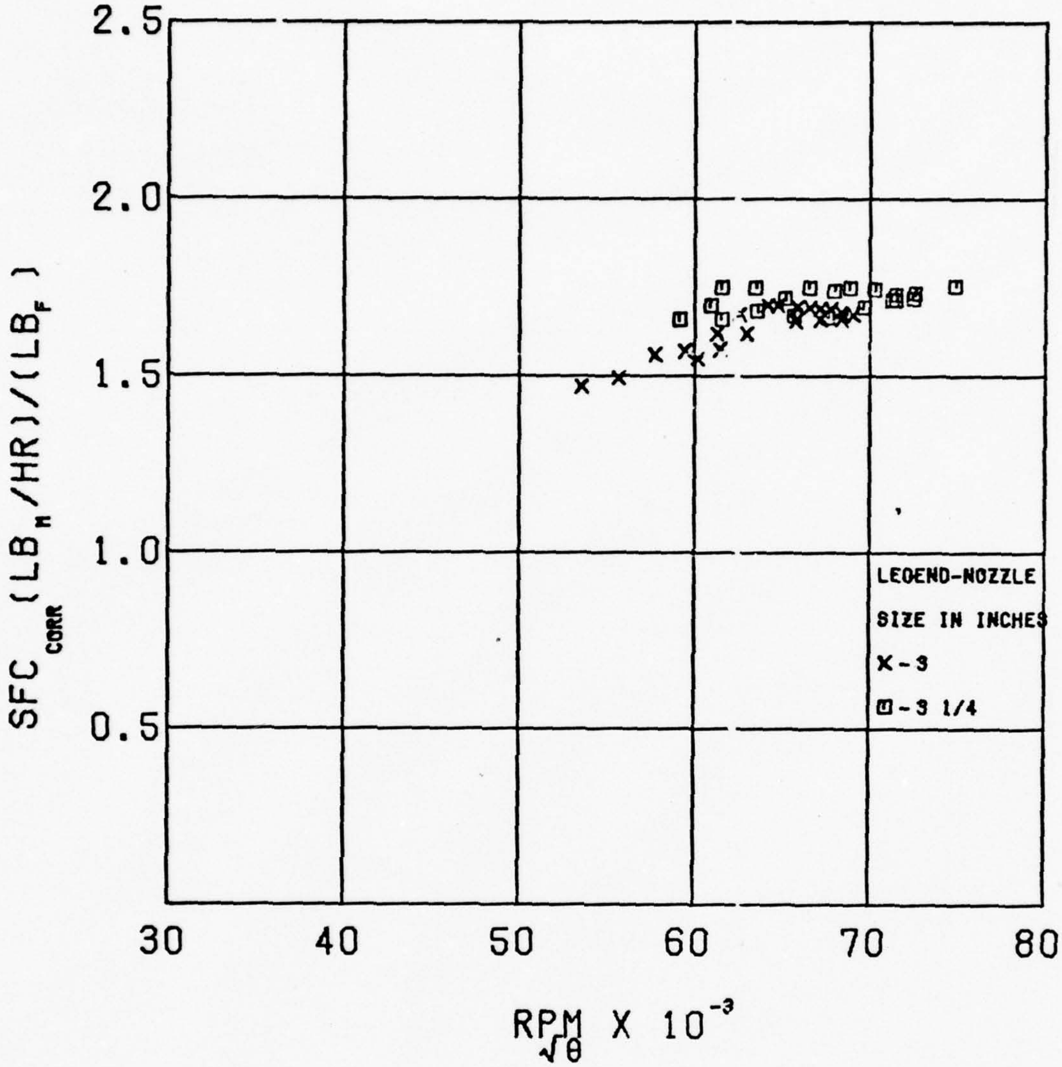


Fig. 11 Specific Fuel Consumption for 1.5 A/R Housing

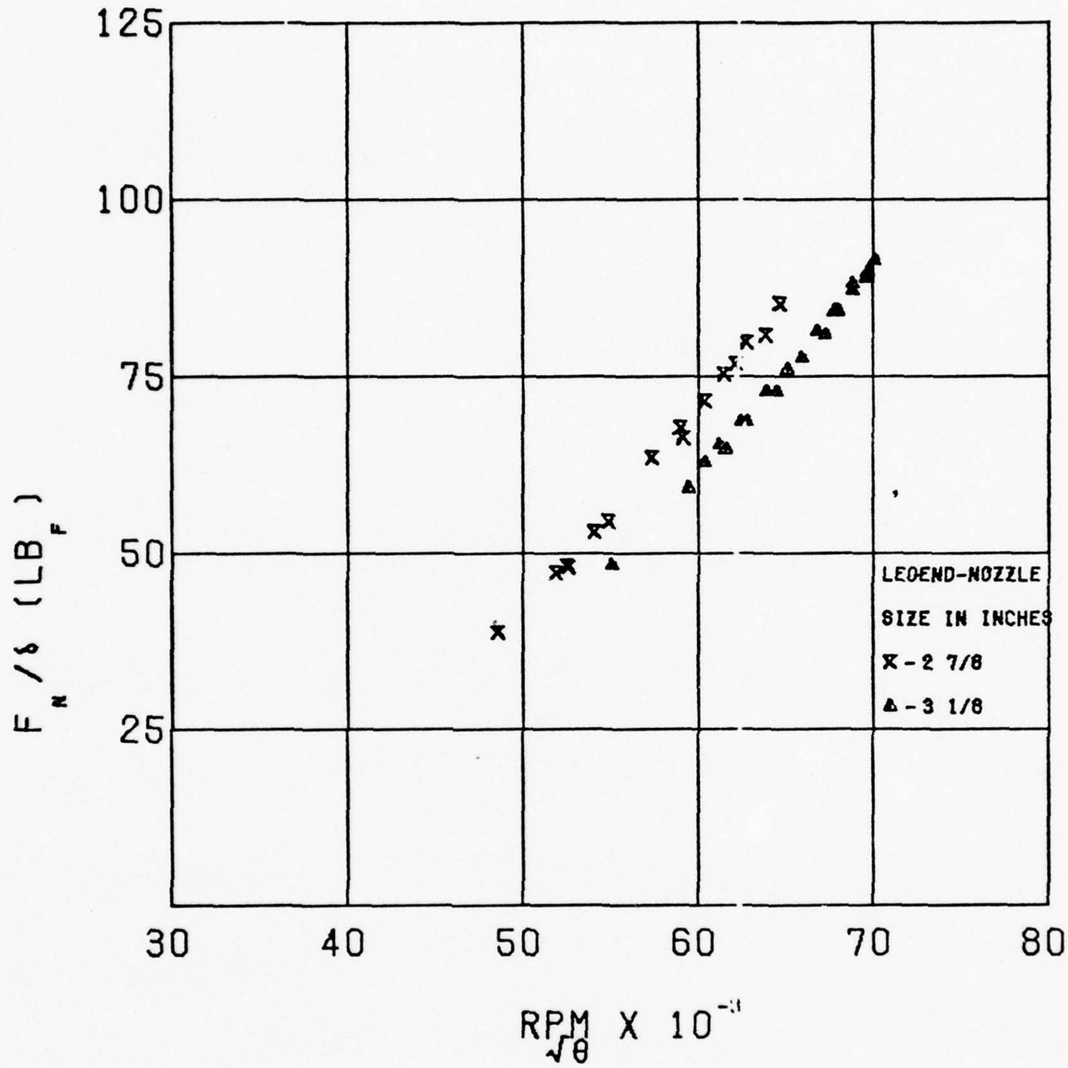


Fig. 12 Thrust for 1.5 A/R Housing

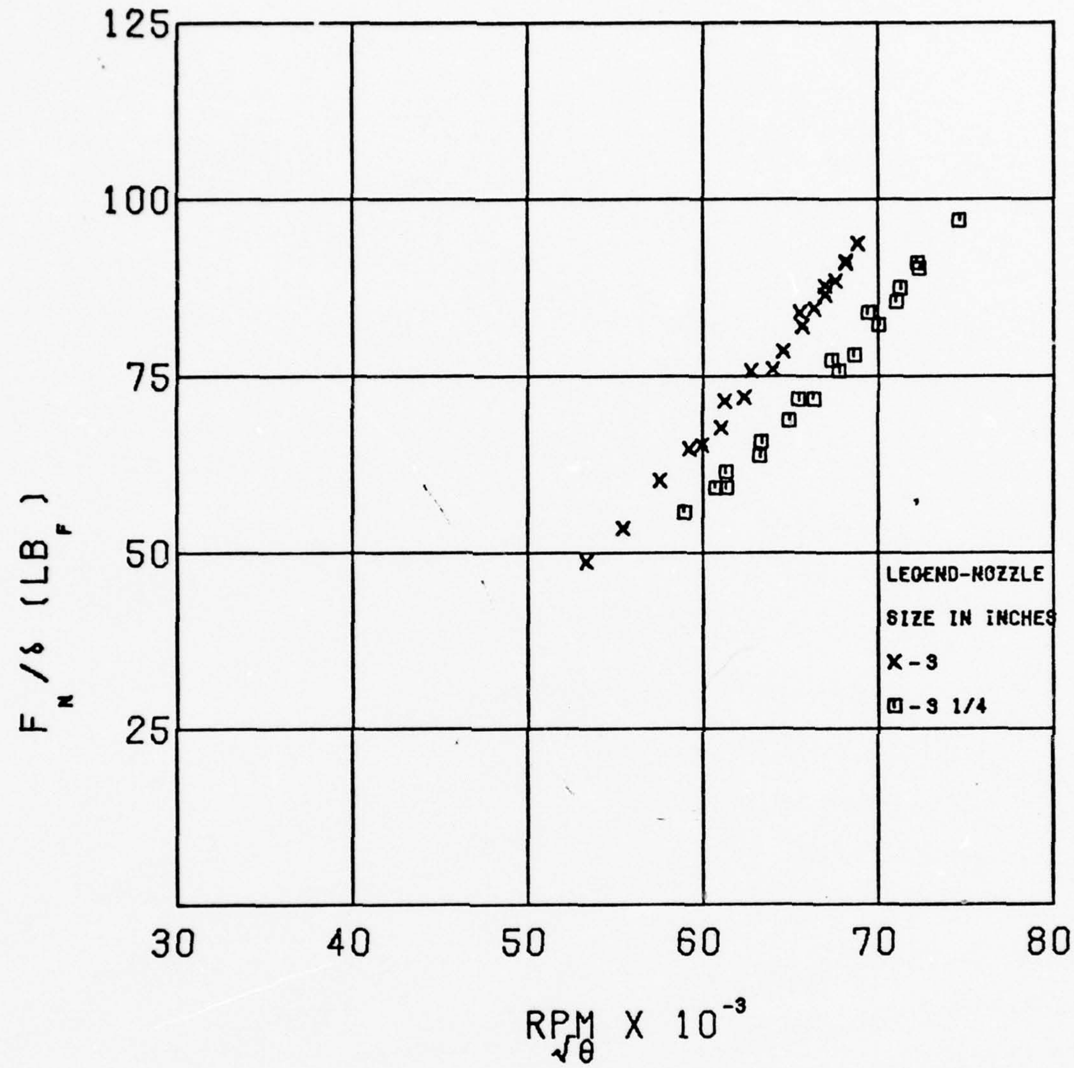


Fig. 13 Thrust for 1.5 A/R Housing

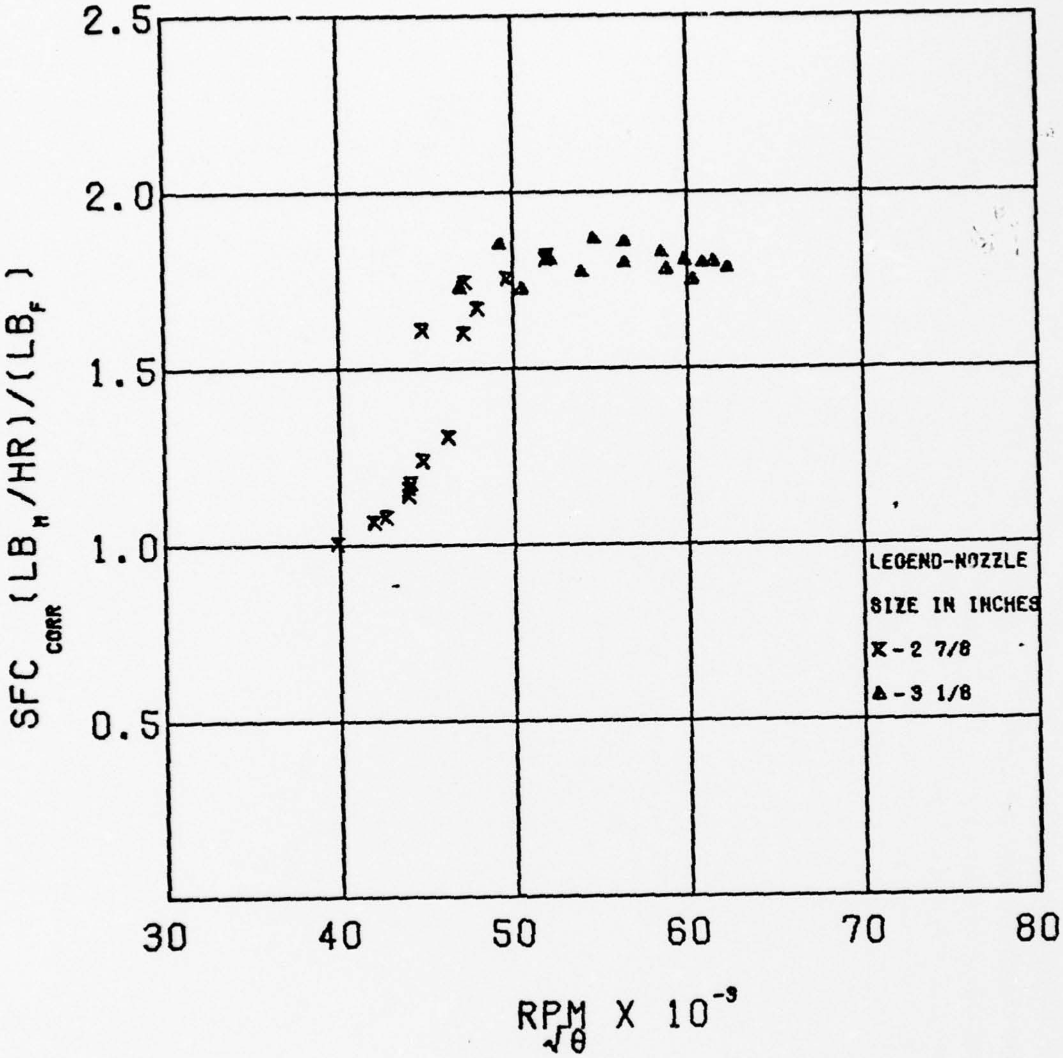


Fig. 14 Specific Fuel Consumption for 1.7 A/R Housing

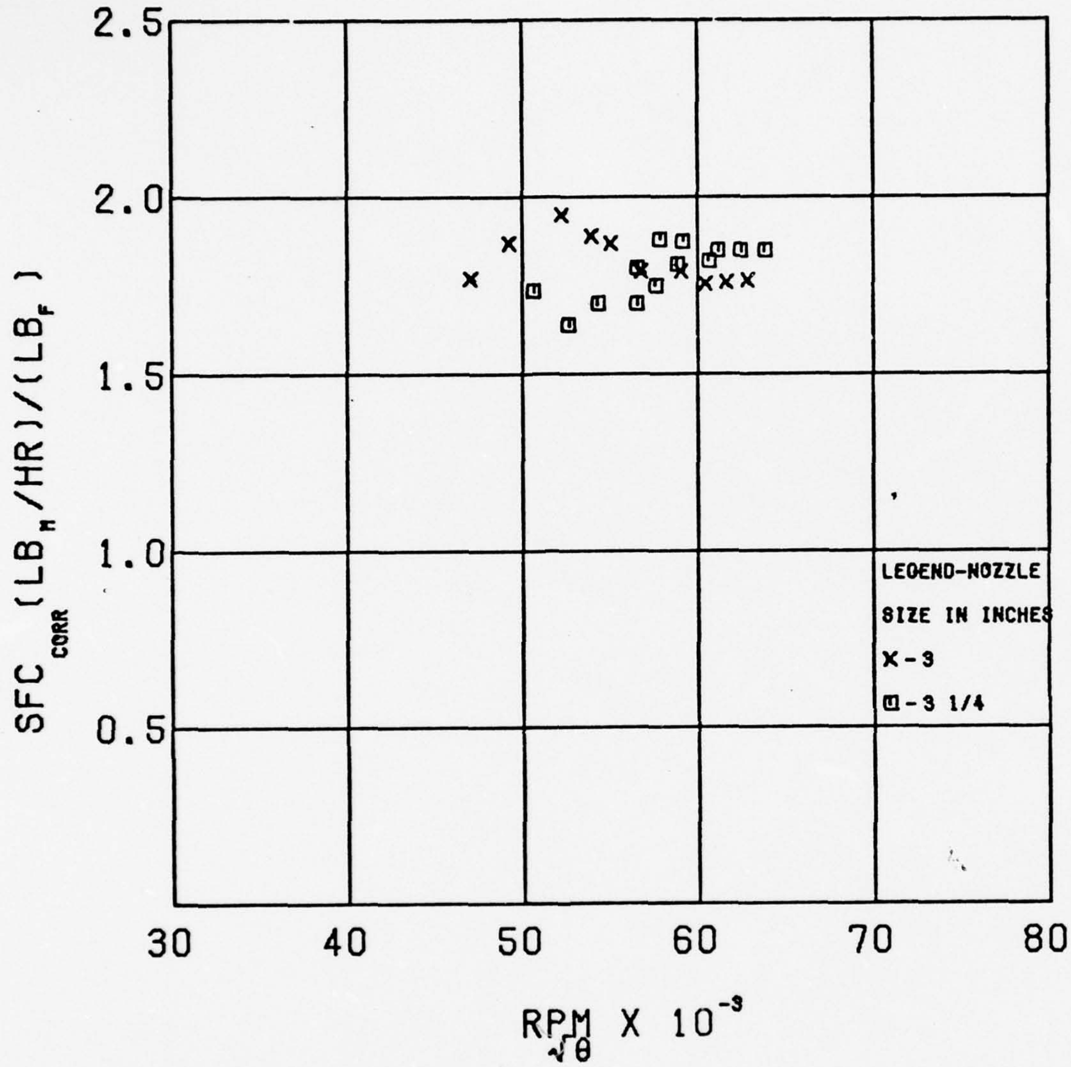


Fig. 15 Specific Fuel Consumption for 1.7 A/R Housing

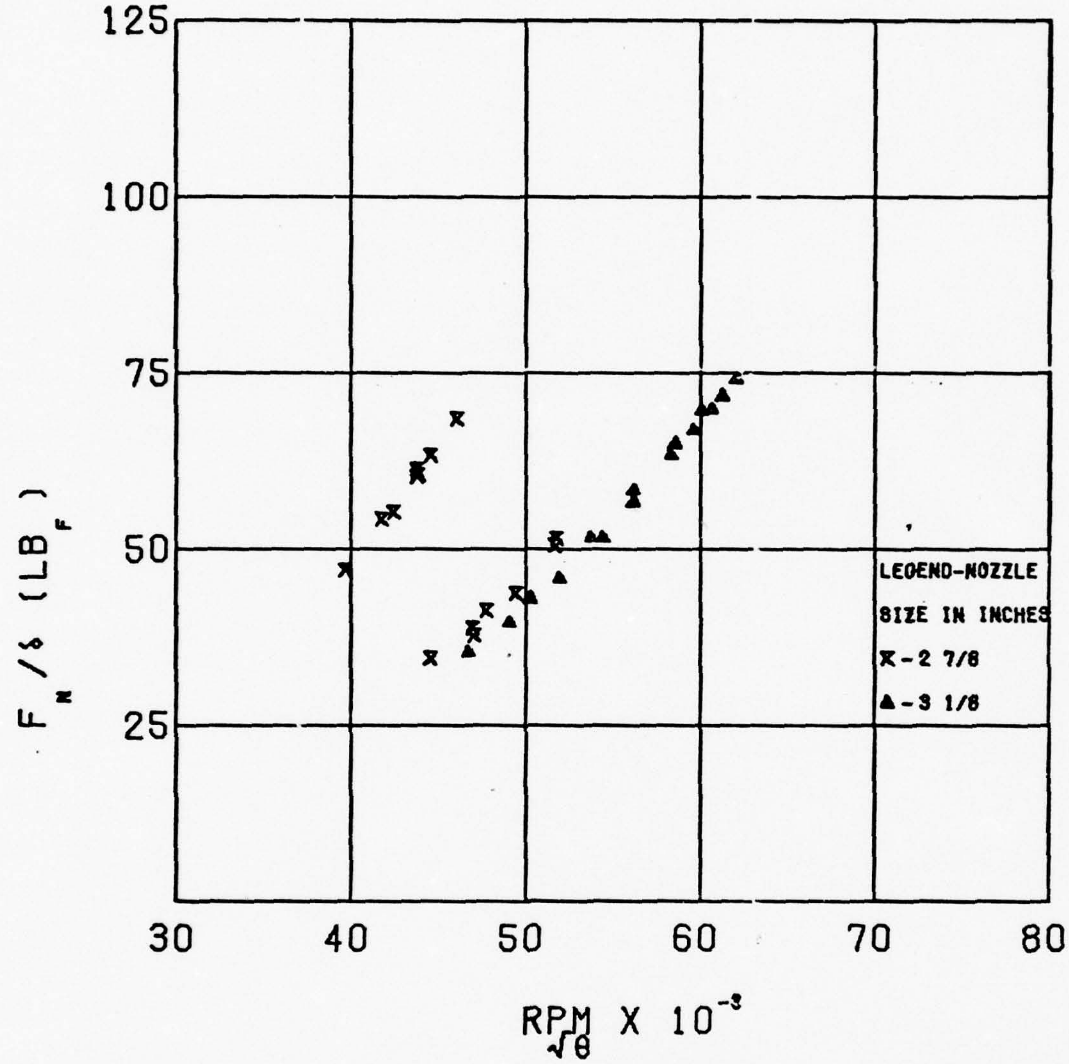


Fig. 16 Thrust for 1.7 A/R Housing

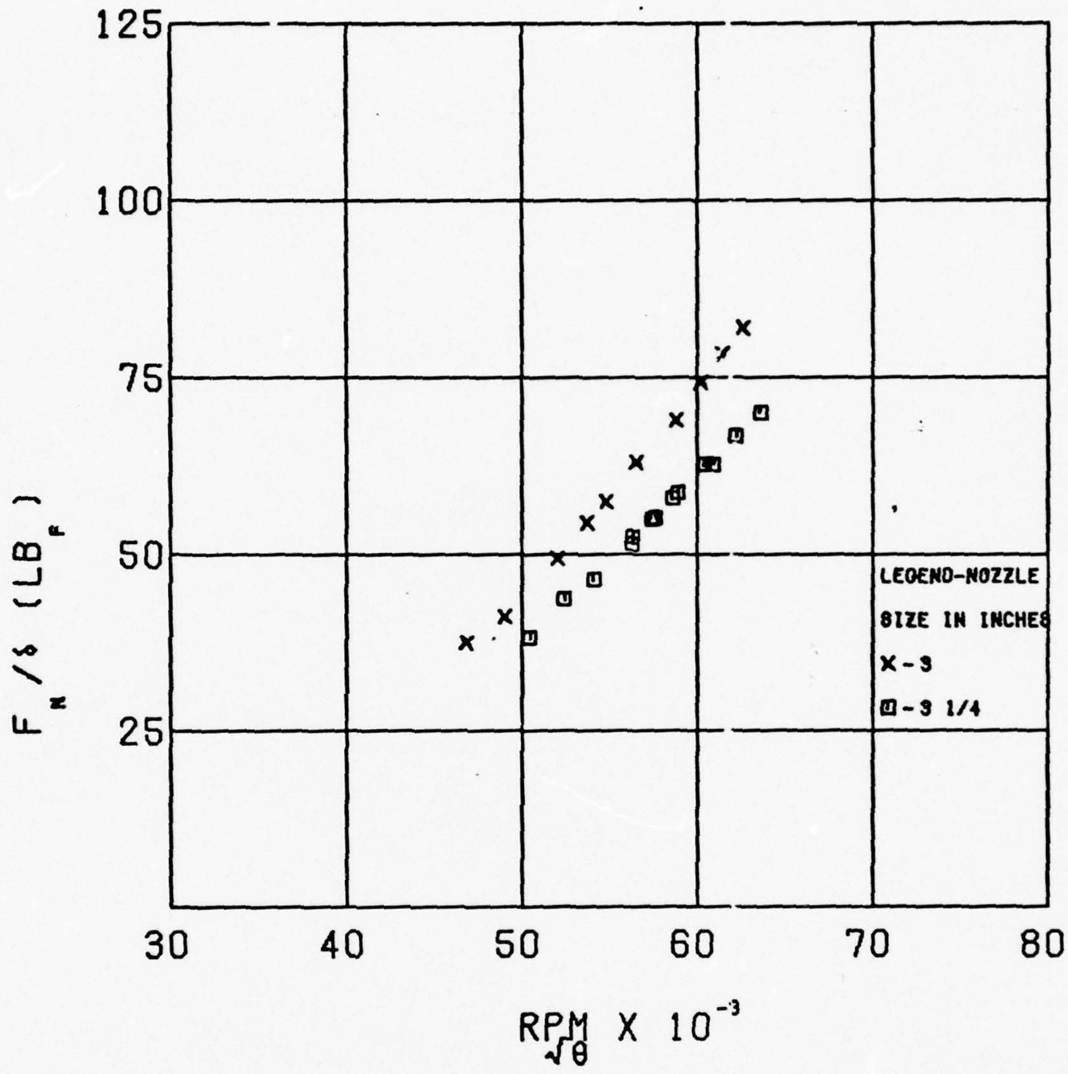


Fig. 17 Thrust for 1.7 A/R Housing

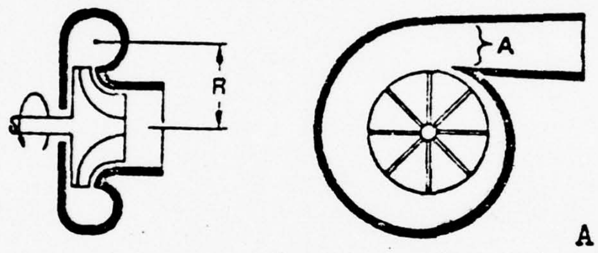
Discussion of Turbine Inlet Temperature Limits

The peaks of the operating lines represent the upper temperature limit which was achieved without destruction of the turbine blades. This was an experimentally determined value of 2000 °F. It is a valid question whether this represents the actual temperature at the turbine blades. In actuality, such a determination would require an elaborate temperature survey which is beyond the scope of this thesis. However, based on observation of engine operation, maximum temperature limits of turbine metals, and measured performance, the value of 2000 °F, as measured at the location shown in Fig. 1(b), was judged sufficiently accurate to approximate the turbine inlet temperature. In all cases, the temperature limit was reached before the flow became choked, and the engine is thus temperature limited. Furthermore, the modified MA1A combustor was capable of supplying all the energy demanded under any operating condition encountered with all configurations, and thus is suitable for continuation testing including augmenter studies.

Turbine Housings

The heavy, cast housing surrounding the turbine serves as a turbine nozzle guide vane and as a protective enclosure for the turbine wheel. It is identified (as used by AiResearch) by an A/R number, which is a

ratio of the throat area of the housing to the distance from the centroid of this area to the center of the turbine wheel (see Fig. 18).



A = area of throat

R = distance from centroid of this area to the center of the turbine wheel

Fig. 18 Turbine Housing A/R Number

The value of the ratio A/R actually determines the amount of power that the turbine extracts from the hot gas. Changing the A/R will change the volume surrounding the turbine wheel and the angle at which the gas impinges on the blades, and thus will cause the turbine (and compressor) to turn at a different rate.

It was found that the optimum A/R for maximum thrust and best SFC was the 1.5. Both the 1.32 A/R and the 1.7 A/R were off-design performing housings compared to the 1.5 A/R. Furthermore, while the 1.32 A/R housing achieved a thrust and mass flow comparable to the 1.7 A/R, a comparison of engine performance shows that the 1.32 A/R achieved the same mass flow at a higher P_{rc} than the 1.7 A/R, or stated another way, for the same P_{rc} the 1.7 A/R produced a higher mass flow. This means that the machine with the 1.32 A/R is less efficient than the machine with the 1.7 A/R and this is seen in the higher SFC for the 1.32 A/R. Thus, the same mass flow is produced at the cost of increased energy, which is dissipated as viscous and thermal losses. In addition, the 1.32 A/R exhibited a much narrower operating range between idle and maximum thrust.

Destructive Testing and Engine Failures

Within the meaning of turbine inlet temperature limits discussed previously, it was observed that the combinations of severe stress and high temperature encountered by the turbine blades was likely to cause a failure after only a short period of operation whenever the temperature was in the range of 2000 to 2200 $^{\circ}F$. When temperatures above 2200 $^{\circ}F$ were encountered, turbine disintegration occurred precipitously, usually before corrective action could be taken. Failures were

instantaneous following onset, but none were sufficiently violent to be considered hazardous.

Initial scheduling of engine tests called for destructive testing to determine failure limits and potentially hazardous failure modes. However, in the course of determining maximum performance, sufficient data was gathered on failures, so that programmed destruct tests were not required.

In all cases, the heavy, cast turbine housing contained the molten metal in the disintegration plane of the turbine, and simply ejected a shower of sparks through the nozzle.

In addition to direct overtemperature, failure could be induced by any malfunction or failure that caused a precipitous loss of airflow when running near the maximum temperature limit. One such failure was caused, in fact, when the compressor impeller came loose on its shaft with resulting compressor and turbine destruction (see Fig. 19).

Although damage was sustained to the equipment during the failures discussed, all engine configurations tested were safe to operate in regard to violent failure.

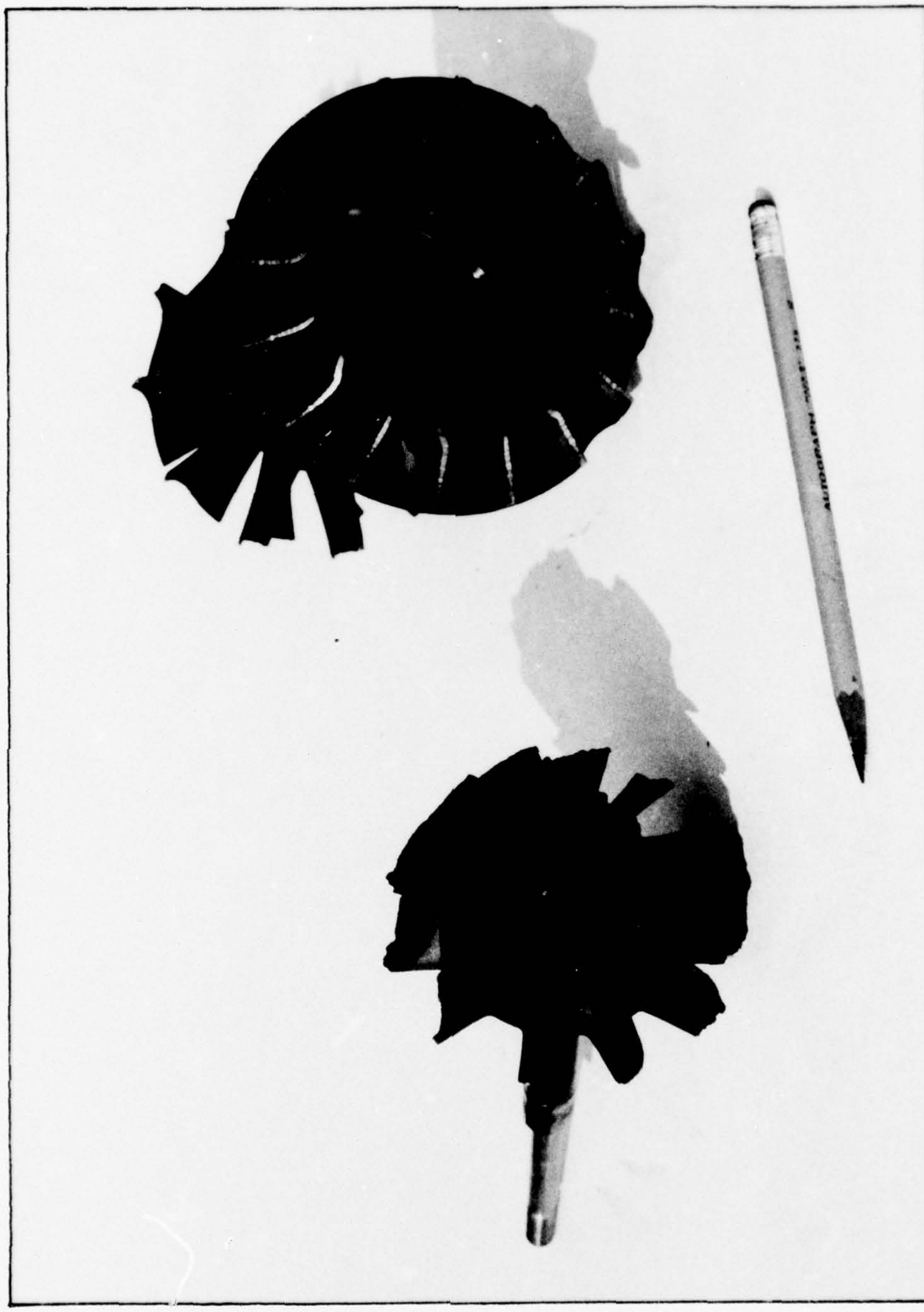


Fig. 19 Turbine Failure (due to loss of airflow)

Fig. 20 Turbine Failure (Comparison of normal turbine with turbine lost following bearing failure and sheared shaft)

IV. Conclusions and Recommendations

Conclusions

The objectives of the thesis were met in that the performance envelopes of all configurations of interest were obtained, together with the optimum and maximum performance configuration. Additionally, with the use of the computer programs listed in Appendix A, similar plots of engine performance, thrust, and SFC are available for future use simply by attaching the appropriate data to the programs.

Specific conclusions are:

(1) Maximum performance is limited by surge and turbine inlet temperature.

(2) The maximum sustained thrust will exceed 5 minutes continuous operation.

(3) The engine will operate for 30 minutes at or below 1800 $^{\circ}$F.

(4) The maximum turbine inlet temperature is 2000 $^{\circ}$F.

(5) Between 2000 and 2200 $^{\circ}$F turbine failure is likely after a short period of operation.

(6) Above 2200 $^{\circ}$F, turbine disintegration occurs precipitously.

(7) The optimum configuration is the A/R 1.5 housing with the 3¼ inch nozzle.

(8) The A/R 1.32 housing is the least suitable for this application.

(9) For a given turbine housing, increasing the nozzle size results in increased weight flow up to the outer instability limit (for the same pressure ratio and turbine inlet temperature).

(10) The maximum temperature limit (2000 ^{o}F, as previously defined) occurs at approximately the same P_{rc} for any size nozzle (for a given turbine housing).

(11) The data is accurate and repeatable (with 5% accuracy).

(12) All configurations are safe to operate in regard to violent failure.

Recommendations

Based on experience with over 22 fully instrumented test runs of the engine, and analysis of all the test results, the following recommendations are made in regard to continued development of the turbocharger derived engine:

(1) Record data from future runs on computer software (e.g., magnetic tape) for greatly reduced data reduction time. With the attachment of such data to the programs already developed, rapid turnaround of results is possible for analysis.

(2) Test only with an operable turbine inlet temperature thermocouple or sensor, as it is considered

essential for testing if inadvertent destruction of the turbine is to be avoided.

(3) Verify maximum endurance (30 minutes) directly.

(4) Improve operating controls on the console to include a direct reading turbine inlet temperature, and either RPM or thrust.

(5) Make limited survey of T_4 to determine an accurate value of temperature at the turbine blades.

(6) Follow with augmenter studies with emphasis on the 1.5 A/R housing, and nozzles 3 inches or larger.

(7) Develop a variable swirl vane assembly to be installed between stations 4 and 5 (turbine and nozzle). While no appreciable swirl was detected at maximum RPM, a swirl component may be desirable in augmented operation.

(8) Develop instrumentation to measure low fuel flow rates to verify SFC curves.

BIBLIOGRAPHY

1. Kent, Tommy J., Conceptual Study for the Development of Low-Cost Turbojets, Thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, March, 1976, Unpublished.

2. Greene, R.L., Combustor Design for a Low-Cost Expendable Jet Engine, Thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, March, 1976. Unpublished.

3. Fisher, C.S., Jr., Remote Engine Control and Instrumentation of a Low-Cost Turbojet Engine, Thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, December, 1976. Unpublished.

4. Witherell, R.E., Design Point Turbine Engine Performance Program. AFAPL TR-68-88, Wright-Patterson AFB, Ohio, Air Force Aero Propulsion Laboratory (Sept. 1968).

Appendix A

Computer Performance Programs

This appendix contains the following computed programs, together with instructions for compiling and attaching data, for plotting on the CDC 6600 computer system using the CALCOMP plotter.

PROGRAM PERF

This program was used to generate the engine operating lines, depicting various nozzle (or other component) performance on a plot of P_{rc} vs W_a.

Program functions are identified by comments to aid in modifying the program such as scale and label changes (this applies to all programs). Although lines are not shown on the plot, to avoid the use of proprietary information, the program contains a calling sequence which will draw a line of maximum adiabatic efficiency, lines of constant RPM, or any line for which coordinates are inserted. The user should supply his own data in the program.

PROGRAM SFC

This program was used to generate both the thrust and the specific fuel consumption of various component configurations, each as a function of RPM.

PROGRAM RPM

This program was used to generate lines of constant RPM by means of a crossplot of P_{rc} and W_a versus RPM. The plots are shown in Appendix B.

```
      PROGRAM PERF(INPUT,OUTPUT,PLOT)
C     ********************************************************************
C     *                                                                  *
C     *  THIS PROGRAM PLOTS PRESSURE RATIO VERSUS WEIGHT FLOW FOR AN    *
C     *  ARBITRARY NUMBER OF OPERATING LINES SPECIFIED IN THE DATA      *
C     *  DECK.  IN ADDITION, IT WILL DRAW A LINE OF CONSTANT ADIABATIC  *
C     *  EFFICIENCY, AND, IF DATA FROM THE PROGRAM RPM ARE INSERTED,    *
C     *  IT WILL DRAW LINES OF CONSTANT RPM.                             *
C     *                                                                  *
C     ********************************************************************
C
C
C
      INTEGER U(10)
      DIMENSION X(100),Y(100)
      DIMENSION LEG(3)
      INTEGER NOZSIZ(7),NOZSYM(7),IND(15),NSARAY(15)
C
C IDENTIFY NOZZLE SIZES
C
      DATA NOZSIZ/5H3 1/4,5H3 1/8,5H3    ,5H2 5/8,
     #5H2 1/2,5H2 7/8,5H2 3/4/
C
C IDENTIFY SYMBOLS USED IN NOZZLE LEGEND FROM CALCOMP GUIDE
C
      DATA NOZSYM/0,2,4,5,6,7,11/
      DATA LEG/10HLEGEND - N,10HOZZLE SIZE,10H IN INCHES/
      CALL PLOT(0.,-3.,-3)
      CALL PLOT (0.,1.0,-3)
      CALL FACTOR (0.6)
```

```
C
C CONSTRUCT WA-PRC AXES
C
      CALL GRID(0.,0.,1.,1.,18,12)
C
C DOUBLES BORDER
C
      CALL PLOT(17.01,11.01,3)
      CALL PLOT(17.01,-0.01,2)
      CALL PLOT(-0.01,-0.01,2)
      CALL PLOT(-0.01,11.01,2)
      CALL PLOT(17.01,11.01,2)
C
C NUMBER WA AXES
C
      DO 10 I=10,30,10
      FPN=130. - I
      A=-0.34
      B=I/10. - 0.79
 10   CALL NUMBER(A,B,0.14,FPN,-90.,-1)
      DO 20 I=10,90,10
      FPN=100.-I
      B=I/10. + 2.14
C
C NUMBER PRC AXES
C
 20   CALL NUMBER(A,B,0.14,FPN,-90.,-1)
      DO 60 I=10,30,10
      FPN=130.-I
      A=17.2
```

```
      B=I/10.-0.79
 60   CALL NUMBER (A,B,0.14,FPN,-90.,-1)
      DO 70 I=10,90,10
      FPN=100.-I
      B=I/10.+2.14
 70   CALL NUMBER (A,B,0.14,FPN,-90.,-1)
      DO 50 I=10,44,2
      FPN=I/10.
      B=-0.2
      A=(I-10.)/2.-0.07
 50   CALL NUMBER(A,B,0.14,FPN,-90.,1)
      DO 80 I=10,44,2
      FPN=I/10.
      B=11.48
      A=(I-10.)/2.-0.07
 80   CALL NUMBER (A,B,0.14,FPN,-90.,1)
      CALL SYMBOL (7.84,11.78,0.28,11H(CORRECTED),0.,11)
      CALL SYMBOL (16.4,9.5,.14,LEG,-90.,30)
      CALL SYMBOL (7.,11.78,0.28,1HP,0.,1)
      CALL SYMBOL (7.28,11.78,0.14,2HRC,0.,2)
      CALL SYMBOL (-.92,8.5,0.28,1HW,-90.,1)
      CALL SYMBOL (-.92,8.22,0.14,1HA,-90.,1)
      CALL SYMBOL (-.92,7.66,0.28,20H(CORRECTED AIR FLOW),-90.,20)
C
C DRAWS LINE OF MAXIMUM ADIABATIC EFFICIENCY, LINES OF CONSTANT RPM,
C OR ANY LINE FOR WHICH COORDINATES ARE INSERTED.  REPLACE NUMBER 7
C IN FOLLOWING STATEMENT WITH THE NUMBER OF LINES TO BE DRAWN IN
C YOUR PROGRAM.
C
      DO 300 I=1,7
```

```
      READ*,N
      READ*,(Y(J),X(J),J=1,N)
      X(N+1)=1.0
      X(N+2)=0.2
      Y(N+1)=120.
      Y(N+2)=-10.
      M=-N
  300 CALL FLINE (X,Y,M,1,0,0)
    1 FORMAT (A10)
  500 FORMAT (A8)
C
C READS AND PLOTS DATA
C
C INSERT DATA CARDS IN FOLLOWING ORDER
C
C     CARD 1 - ENTER NUMBER OF SETS OF DATA
C     CARD 2 - ENTER HOUSING A/R SIZE
C     CARD 3 - BLANK CARD
C     CARD 4 - ENTER SYMBOL FOR NOZZLE SIZE FROM CALCOMP PLOTTER GUIDE,
C              PAGE 45
C     CARD 5 - ENTER DATE OR LEAVE BLANK
C     CARD 6 - ENTER A/R NUMBER OR LEAVE BLANK
C     CARD 7 - ENTER NOZZLE SIZE IN INCHES
C     CARD 8 - ENTER T INFINITY IN DEGREES R
C     CARD 9 - ENTER P INFINITY IN PSI
C     CARD 10 - ENTER RUN TIME OR LEAVE BLANK
C     CARD 11 - ENTER NUMBER OF DATA POINTS TO BE PLOTTED
C     CARD 12 - BEGIN DATA
C
C PARAMETERS ON DATA CARDS ARE THREE DIGIT FIXED-POINT NUMBERS.
```

```
C THEY ARE SEPARATED BY A SINGLE SPACE AND THE FIRST NUMBER
C BEGINS IN COLUMN TWO.  THEY ARE LISTED IN THIS PROGRAM IN THE
C FOLLOWING ORDER:  P3, P4, P5, T3, T4, T5, F/F, THRUST, RPM,
C AND WEIGHT FLOW.
C
      READ*,NSETS
      READ 200,IAR
 200  FORMAT (A4)
      DO 240 I=1,NSETS
      READ 210,NSIZ
 210  FORMAT (4(/),A5)
      READ*,TINF
      READ*,PINF
      READ 1,TIME
      READ*,N
      DO 600 L=1,N
C
C READ PARAMETERS ON DATA CARDS AND PERFORM CALCULATIONS FOR
C CORRECTED PRESSURE RATIO AND WEIGHT FLOW. VALUES ARE CORRECTED
C TO THE TEMPERATURE AND PRESSURE READ ON DATA CARDS 8 AND 9 ABOVE.
C
      READ 510,U
 510  FORMAT(10I4)
C
C CONVERT P3 TO INCHES MEASURED BY STRIP RECORDER
C
      X(L)=FLOAT(J(1))/100.
C
C CONVERT TO PRESSURE (1 INCH = 10 PSI) AND COMPUTE PRC CORRECTED
C
```

```
      X(L) = (X(L)*10.+ PINF)/PINF
C
C CONVERT WEIGHT FLOW TO INCHES MEASURED BY STRIP RECORDER
C
      Y(L)=FLOAT(J(10))/100.
C
C COMPUTE WEIGHT FLOW (UNCORRECTED) - REF FISHER
C
      Y(L)=111.24*SQRT((PINF*2.*Y(L))/(.4913*TINF))
C
C NOTE: 111.24 = (1.8868)(.9826)(60)
C
C COMPUTE CORRECTED WEIGHT FLOW
C
      Y(L)=(14.7*Y(L)*SQRT(TINF/518.7))/(PINF)
C
C SCALE CHANGE TO POSITION ORIGIN
C
      X(L)=(X(L)-1.0)/.2
      Y(L)=(Y(L)-120.)/(-10.)
C
C IDENTIFY INDEX NUMBERS OF SYMBOLS USED IN LEGEND
C
      DO 800 J=1,7
      IF(NOZSIZ(J).EQ.NSIZ) IND(I)=J
800   CONTINUE
      NS=NOZSYM(IND(I))
      CALL SYMBOL (X(L),Y(L),0.14,NS,-90.,-1)
  600 CONTINUE
 240  CONTINUE
```

```
C
C PUT LEGEND ON GRAPH
C
      KK=1
      NSARAY(1)=IND(1)
      DO 820 J=2,NSETS
      DO 850 I=1,KK
      IF(NSARAY(I).EQ.IND(J)) GO TO 820
  850 CONTINUE
      KK=KK+1
      NSARAY(KK)=IND(J)
  820 CONTINUE
      K=1H-
      A=15.4
      AA=15.33
      B=9.5
      C=9.30
      D=9.10
      DO 840 J=1,KK
      NS=NOZSYM(NSARAY(J))
      CALL SYMBOL(A,B,.14,NS,-90.,-1)
      CALL SYMBOL(AA,C,.14,K,-90.,1)
      CALL SYMBOL(AA,D,.14,NOZSIZ(NSARAY(J)),-90.,5)
      A=A-1.
      AA=AA-1.
840   CONTINUE
  350 CALL PLOT(20.,0.,-3)
      CALL PLOTE(N)
      STOP
      END
```

```
      PROGRAM SFC(INPUT,OUTPUT ,PLOT)
C     ******************************************************************
C     *                                                                *
C     *  THIS PROGRAM PLOTS CORRECTED VALUES OF SPECIFIC FUEL          *
C     *  CONSUMPTION AND THRUST VERSUS RPM, EACH ON A SEPARATE GRID.   *
C     *                                                                *
C     ******************************************************************
C
C
      REAL X(100), Y(100),R(100)
      INTEGER U(10)
      INTEGER LEG1(2),LEG2(2)
      INTEGER NOZSIZ(7),NOZSYM(7),IND(15)
      DIMENSION NSARAY(7)
C
C IDENTIFY NOZZLE SIZES
C
      DATA NOZSIZ/5H3 1/4,5H3 1/8,5H3     ,5H2 5/8,
     #5H2 1/2,5H2 7/8,5H2 3/4/
C
C IDENTIFY SYMBOLS USED IN NOZZLE LEGEND FROM CALCOMP GUIDE
C
      DATA NOZSYM/0,2,4,5,6,7,11/
      DATA LEG1/10HLEGEND-NOZ,3HZLE/
      DATA LEG2/10HSIZE IN IN,4HCHES/
      CALL PLOT(0.,3.,-3)
C
C CONSTRUCT RPM-FN AXES
C
      CALL GRID(0.,0.,1.,1.,6,6)
```

```
C
C NUMBER RPM AXIS
C
      B=-.28
      DO 10 I=30,80,10
      FPN=I
      A=(I-30.)/10.-.14
 10   CALL NUMBER(A,B,.14,FPN,0.,-1)
C NUMBER FN AXIS
C
      A=-.28
      DO 20 I=25,125,25
      FPN=I
      B= I/25-.07
      IF(I.GE.100) A=-.42
 20   CALL NUMBER(A,B,.14,FPN,0.,-1)
C
C LABEL RPM AXIS
C
      CALL SYMBOL(2.,-.75,.14,8HRPM X 10,0.,8)
      CALL SYMBOL(2.14,-0.89,.14,25,0.,-1)
      CALL SYMBOL(2.28,-0.89,.14,132,0.,-1)
      CALL SYMBOL(3.12,-.61,.07,2H-3,0.,2)
C
C LABEL FN AXIS
C
      A=-.75
      B=1.
      CALL SYMBOL(A,B,.14,10HF /  (LB ),90.,10)
      CALL SYMBOL(A,1.42,.14,94,90.,-1)
```

```
      A=-.61
      B=1.14
      CALL SYMBOL(A,B,.07,1HN,90.,1)
      B=2.12
      CALL SYMBOL(A,B,.07,1HF,90.,1)
C
C CONSTRUCT RPM-SFC AXES SYSTEM
C
      CALL PLOT(8.,0.,-3)
      CALL GRID(0.,0.,1.,1.,5,5)
C
C NUMBER RPM AXIS
C
      B=-.28
      DO 40 I=30,80,10
      FPN=I
      A=(I-30.)/10.-.14
 40   CALL NUMBER(A,B,.14,FPN,0.,-1)
C
C LABEL RPM AXIS
C
      CALL SYMBOL(2.,-.75,.14,8HRPM X 10,0.,8)
      CALL SYMBOL(2.14,-0.89,.14,25,0.,-1)
      CALL SYMBOL(2.28,-0.89,.14,132,0.,-1)
      CALL SYMBOL(3.12,-.61,.07,2H-3,0.,2)
C
C NUMBER SFC AXIS
C
      CALL NUMBER(-.42,0.93,.14,.5,0.,1)
      A=-.42
```

```
      DO 30 I=1,4
      FPN=1+(I-1)*.5
      B=I+.93
 30   CALL NUMBER(A,B,.14,FPN,0.,1)
C
C LABEL SFC AXIS
C
      A=-.75
      B=1.
      CALL SYMBOL(A,B,.14,19HSFC  (LB /HR)/(LB ),90.,19)
      A=-.68
      B=2.14
      CALL SYMBOL(A,B,.07,1HM,90.,1)
      B=3.36
      CALL SYMBOL(-.61,1.42,.07,4HCORR,90.,4)
      CALL SYMBOL(A,B,.07,1HF,90.,1)
C
C READS AND PLOTS DATA
C
C INSERT DATA CARDS IN FOLLOWING ORDER
C
C      CARD 1 - ENTER NUMBER OF SETS OF DATA
C      CARD 2 - ENTER HOUSING A/R SIZE
C      CARD 3 - BLANK CARD
C      CARD 4 - ENTER SYMBOL FOR NOZZLE SIZE FROM CALCOMP PLOTTER GUIDE,
C      PAGE 45
C      CARD 5 - ENTER DATE OR LEAVE BLANK
C      CARD 6 - ENTER A/R NUMBER OR LEAVE BLANK
C      CARD 7 - ENTER NOZZLE SIZE IN INCHES
C      CARD 8 - ENTER T INFINITY IN DEGREES R
```

```
C      CARD 9 - ENTER P INFINITY IN PSI
C      CARD 10 - ENTER RUN TIME OR LEAVE BLANK
C      CARD 11 - ENTER NUMBER OF DATA POINTS TO BE PLOTTED
C      CARD 12 - BEGIN DATA
C
C PARAMETERS ON DATA CARDS ARE THREE DIGIT FIXED-POINT NUMBERS.
C THEY ARE SEPARATED BY A SINGLE SPACE AND THE FIRST NUMBER
C BEGINS IN COLUMN TWO.  THEY ARE LISTED IN THIS PROGRAM IN THE
C FOLLOWING ORDER:  P3, P4, P5, T3, T4, T5, F/F, THRUST, RPM,
C AND WEIGHT FLOW.
C
       READ*,NSETS
       READ 100,IAR
 100   FORMAT (A4)
       DO 140 I=1,NSETS
       READ 110,NSIZ
 110   FORMAT (4(/),A5)
       READ*,TINF
       READ*,PINF
       THETA=TINF/518.7
       DELTA=PINF/14.7
       READ 100,TIME
       READ *,N
 120   FORMAT(10I4)
       DO 130 J=1,N
C
C READ PARAMETERS ON DATA CARDS AND PERFORM CALCULATIONS FOR
C CORRECTED SFC, THRUST, AND RPM.  VALUES ARE CORRECTED TO
C THE TEMPERATURE AND PRESSURE READ ON DATA CARDS 8 AND 9 ABOVE.
C
```

```
      READ 120,J
C
C CONVERTS INCHES ON STRIP RECORDER TO F/F IN LB/HR (CORRECTED)
C
      X(J)=FLOAT(J(7))*.27083/(DELTA*SQRT(THETA))
C
C NOTE:  .27083 = (325/180) (.75) (HZ) WHERE (325/180) = SLOPE
C OF THE CORRECTION CURVE FOR THE MODEL THM - 005, .75 = SPECIFIC
C GRAVITY, AND 1 INCH = 20 HZ.
C
C CONVERTS INCHES ON STRIP RECORDER TO THRUST (CORRECTED)
C
      Y(J)=FLOAT(J(8))*.20/DELTA
C
C COMPUTES SFC
C
      X(J)=X(J)/Y(J)
C
C CONVERTS INCHES ON STRIP RECORDER TO RPM (CORRECTED)
C 1 INCH = 12000 RPM
C
 130  R(J)=FLOAT(J(9))*120./SQRT(THETA)/1000.
C
C IDENTIFY INDEX NUMBERS OF SYMBOLS USED IN GRAPH
C
      DO 800 J=1,7
      IF(NOZSIZ(J).EQ.NSIZ) IND(I)=J
800   CONTINUE
      DO 150 J=1,N
      XP=X(J)/.5
```

```
      RP=(R(J)-30.)/10.
      NS=NOZSYM(IND(I))
 150  CALL SYMBOL (RP,XP,.07,NS,0.,-1)
      CALL PLOT(-8.,0.,-3)
      DO 160 J=1,N
      YP=Y(J)/25.
      RP=(R(J)-30.)/10.
 160  CALL SYMBOL (RP,YP,.07,NS,0.,-1)
      IF(I.EQ.NSETS) GO TO 140
      CALL PLOT(8.,0.,-3)
 140  CONTINUE
C
C PUT LEGEND ON GRAPH
C
      KK=1
      NSARAY(1)=IND(1)
      DO 820 J=2,NSETS
      DO 850 I=1,KK
      IF(NSARAY(I).EQ.IND(J)) GO TO 820
 850  CONTINUE
      KK=KK+1
      NSARAY(KK)=IND(J)
 820  CONTINUE
      DO 860 L=1,2
      A=4.10
      B=1.84
      CALL SYMBOL(A,B,.07,LEG1,0.,13)
      B=B-.25
      CALL SYMBOL(A,B,.07,LEG2,0.,14)
      K=1H-
```

```
      A=4.13
      B=1.37
      AA=4.23
      C=1.34
      AB=4.33
      DO 830 M=1,KK
      NS=NOZSYM(NSARAY(M))
840   CALL SYMBOL(A,B,.07,NS,0.,-1)
      CALL SYMBOL(AA,C,.07,K,0.,1)
      CALL SYMBOL(AB,C,.07,NOZSIZ(NSARAY(M)),0.,5)
      B=B-.25
      C=C-.25
830   CONTINUE
      IF(L.EQ.1) CALL PLOT(8.,0.,-3)
850   CONTINUE
      CALL PLOT(10.,0.,-3)
      CALL PLOTE(N)
      STOP
      END
```

```
      PROGRAM RPM(INPUT,OUTPUT,PLOT)
C     ******************************************************************
C     *                                                                *
C     *  THIS PROGRAM PLOTS CORRECTED VALUES OF PRESSURE RATIO AND     *
C     *  WEIGHT FLOW VERSUS RPM.  VALUES OF PRESSURE RATIO ARE READ    *
C     *  FROM THE LOWER CURVES ON THE RIGHT HAND SCALE AND VALUES OF   *
C     *  WEIGHT FLOW FROM THE UPPER CURVES ON THE LEFT HAND SCALE.     *
C     *  THE PRESSURE RATIO/WEIGHT FLOW COORDINATES ARE THEN INSERTED  *
C     *  INTO THE PERF PROGRAM WHICH WILL DRAW LINES OF CONSTANT RPM.  *
C     *                                                                *
C     ******************************************************************
C
C
      REAL X(100),Y(100),R(100)
      INTEGER U(10)
      DIMENSION LEG1(2),LEG2(2)
      INTEGER NOZSIZ(7),NOZSYM(7),IND(15)
      DIMENSION NSARAY(15)
C
C IDENTIFY NOZZLE SIZES
C
      DATA NOZSIZ/5H3 1/4,5H3 1/8,5H3     ,5H2 5/8,
     #5H2 1/2,5H2 7/8,5H2 3/4/
C
C IDENTIFY SYMBOLS USED IN NOZZLE LEGEND FROM CALCOMP GUIDE
C
      DATA NOZSYM/0,2,4,5,6,7,11/
      DATA LEG1/10HLEGEND - N,5HOZZLE/
      DATA LEG2/10HSIZE IN IN,4HCHES/
      CALL PLOT(0.,1.,-3)
```

```
C
C NUMBER PRC AXIS
C
      CALL GRID(0.,0.,1.,1.,12,3)
      B=-.14
      DO 60 I=1,7
      FPN=1.+(I-1)*.5
      A=I-1.07
 60   CALL NUMBER(A,B,.14,FPN,-30.,1)
C
C NUMBER RPM AXIS
C
      A=-.28
      DO 10 I=10,30,10
      FPN=100-I
      B=I/10-0.36
 10   CALL NUMBER(A,B,.14,FPN,-30.,-1)
      CALL NUMBER(+.93,7.23,.14,0,-90.,-1)
C
C NUMBER WA AXIS
C
      B=7.42
      DO 40 I=10,120,10
      IF(I.GE.100) B=7.56
      FPN=I
      A=(I-20)/10+.93
 40   CALL NUMBER(A,B,.14,FPN,-30.,-1)
C
C LABEL WA AXIS
C
```

```
      A=4.
      B=8.
      CALL SYMBOL(A,B,.14,1HW,0.,1)
      C=A+.14
      D=B-.07
      CALL SYMBOL(C,D,.07,8HA (CORR),0.,8)
      C=A+.63
      CALL SYMBOL(C,B,.14,10H (LB /MIN),0.,10)
      C=A+1.21
      CALL SYMBOL(C,D,.07,1HF,0.,-1)
      CALL SYMBOL(C,D,.07,1HF,0., 1)
C
C LABEL PRC AXIS
C
      B=-1.
      CALL SYMBOL(A,B,.14,1HP,0.,1)
      D=B-.07
      C=A+.14
      CALL SYMBOL(C,D,.07,9HRC (CORR),0.,9)
C
C LABEL RPM AXIS
C
C
      A=-1.
      B=4.5
      CALL SYMBOL(A,B,.14,9HRPM   X10,-90.,9)
      B=4.08
      A=-1.07
      CALL SYMBOL(-.85,3.24,.07,2H-3,-90.,2)
      CALL SYMBOL(A,B,.07,6H(CORR),-90.,6)
```

```
C
C READS AND PLOTS DATA
C
C INSERT DATA CARDS IN FOLLOWING ORDER
C
C      CARD 1 - ENTER NUMBER OF SETS OF DATA
C      CARD 2 - ENTER HOUSING A/R SIZE
C      CARD 3 - BLANK CARD
C      CARD 4 - ENTER SYMBOL FOR NOZZLE SIZE FROM CALCOMP PLOTTER GUIDE,
C      PAGE 45
C      CARD 5 - ENTER DATE OR LEAVE BLANK
C      CARD 6 - ENTER A/R NUMBER OR LEAVE BLANK
C      CARD 7 - ENTER NOZZLE SIZE IN INCHES
C      CARD 8 - ENTER T INFINITY IN DEGREES R
C      CARD 9 - ENTER P INFINITY IN PSI
C      CARD 10 - ENTER RUN TIME OR LEAVE BLANK
C      CARD 11 - ENTER NUMBER OF DATA POINTS TO BE PLOTTED
C      CARD 12 - BEGIN DATA
C
C PARAMETERS ON DATA CARDS ARE THREE DIGIT FIXED-POINT NUMBERS.
C THEY ARE SEPARATED BY A SINGLE SPACE AND THE FIRST NUMBER
C BEGINS IN COLUMN TWO.  THEY ARE LISTED IN THIS PROGRAM IN THE
C FOLLOWING ORDER:  P3, P4, P5, T3, T4, T5, F/F, THRUST, RPM,
C AND WEIGHT FLOW.
C
       READ*,NSETS
       READ 200,IAR
 200   FORMAT (A4)
       DO 240 I=1,NSETS
       READ 210,NSIZ
```

```
 210   FORMAT (4(/),A5)
       READ*,TINF
       READ*,PINF
       READ 200,TIME
       READ *,N
 220   FORMAT(10I4)
       THETA=(TINF)/518.7
       DO 230 L=1,N
C
C READ PARAMETERS ON DATA CARDS AND PERFORM CALCULATIONS FOR
C CORRECTED PRESSURE RATIO, WEIGHT FLOW, AND RPM.  VALUES ARE
C CORRECTED TO THE TEMPERATURE AND PRESSURE READ ON DATA CARDS
C 8 AND 9 ABOVE.
C
       READ 220,J
C
C CONVERT P3 TO INCHES MEASURED BY STRIP RECORDER
C
       X(L)=FLOAT(J(1))/100.
C
C CONVERT WEIGHT FLOW TO INCHES MEASURED BY STRIP RECORDER
C
       Y(L)=FLOAT(J(10))/100.
C
C COMPUTE WEIGHT FLOW (UNCORRECTED) - REF FISHER
C
       Y(L)=111.24*SQRT((PINF*2.*Y(L))/(.4913*TINF))
C
C NOTE: 111.24 = (1.8868)(.9826)(60)
C
```

```
C
C COMPUTE CORRECTED WEIGHT FLOW
C
      Y(L)=(14.7*Y(L)*SQRT(TINF/518.7))/(PINF)
C
C CONVERT TO PRESSURE (1 INCH = 10 PSI) AND COMPUTE PRC CORRECTED
C
      X(L) = (X(L)*10.+ PINF)/PINF
C
C COMPUTE CORRECTED RPM
C
 230  R(L)=FLOAT(J(9))*120./SQRT(THETA)/1000.
C
C IDENTIFY INDEX NUMBERS OF SYMBOLS USED IN LEGEND
C
      DO 800 J=1,7
      IF(NOZSIZ(J).EQ.NSIZ) IND(I)=J
800   CONTINUE
      NS=NOZSYM(IND(I))
      DO 250 J=1,N
      RP=-(R(J)-90.)/10.
      XP=(X(J)-1.)/.5
 250  CALL SYMBOL(XP,RP,.14,NS,-90.,-1)
      DO 260 J=1,N
      RP=-(R(J)-90.)/10.
      YP=(Y(J)-10.)/10.
260   CALL SYMBOL(YP,RP,.14,NS,-90.,-1)
 240  CONTINUE
      K=1H-
      A=10.7
```

```
      B=6.5
      CALL SYMBOL(A,3,.14,LEG1,-90.,15)
      A=10.1
      CALL SYMBOL(A,B,.14,LEG2,-90.,14)
      KK=1
      NSARAY(1)=IND(1)
      DO 820 J=2,NSETS
      DO 850 I=1,KK
      IF(NSARAY(I).EQ.IND(J)) GO TO 820
  850 CONTINUE
      KK=KK+1
      NSARAY(KK)=IND(J)
  820 CONTINUE
      A=9.47
      B=6.43
      AA=9.4
      C=6.23
      D=6.03
      DO 840 L=1,KK
      NS=NOZSYM(NSARAY(L))
      CALL SYMBOL(A,B,.14,NS,-90.,-1)
      CALL SYMBOL(AA,C,.14,K,-90.,1)
      CALL SYMBOL(AA,D,.14,NOZSIZ(NSARAY(L)),-90.,5)
      A=A-1.
      AA=AA-1.
  840 CONTINUE
      CALL PLOT(1+.,0.,-3)
      CALL PLOTE(N)
      STOP
      END
```

Appendix B

Plots For Determining Lines Of Constant RPM

This appendix contains the crossplots of air flow and pressure ratio, each versus RPM for each of the three turbine housings tested (Figs. 21 through 26). Since the pressure ratio is a linear function of the RPM, lines of constant RPM will appear in Figs. 3, 4, and 5 as a horizontal line. These plots are used both to obtain an estimate of the operating RPM in Figs. 3, 4, and 5 and as a check on the data since any deviation from the linear plot is easily detected.

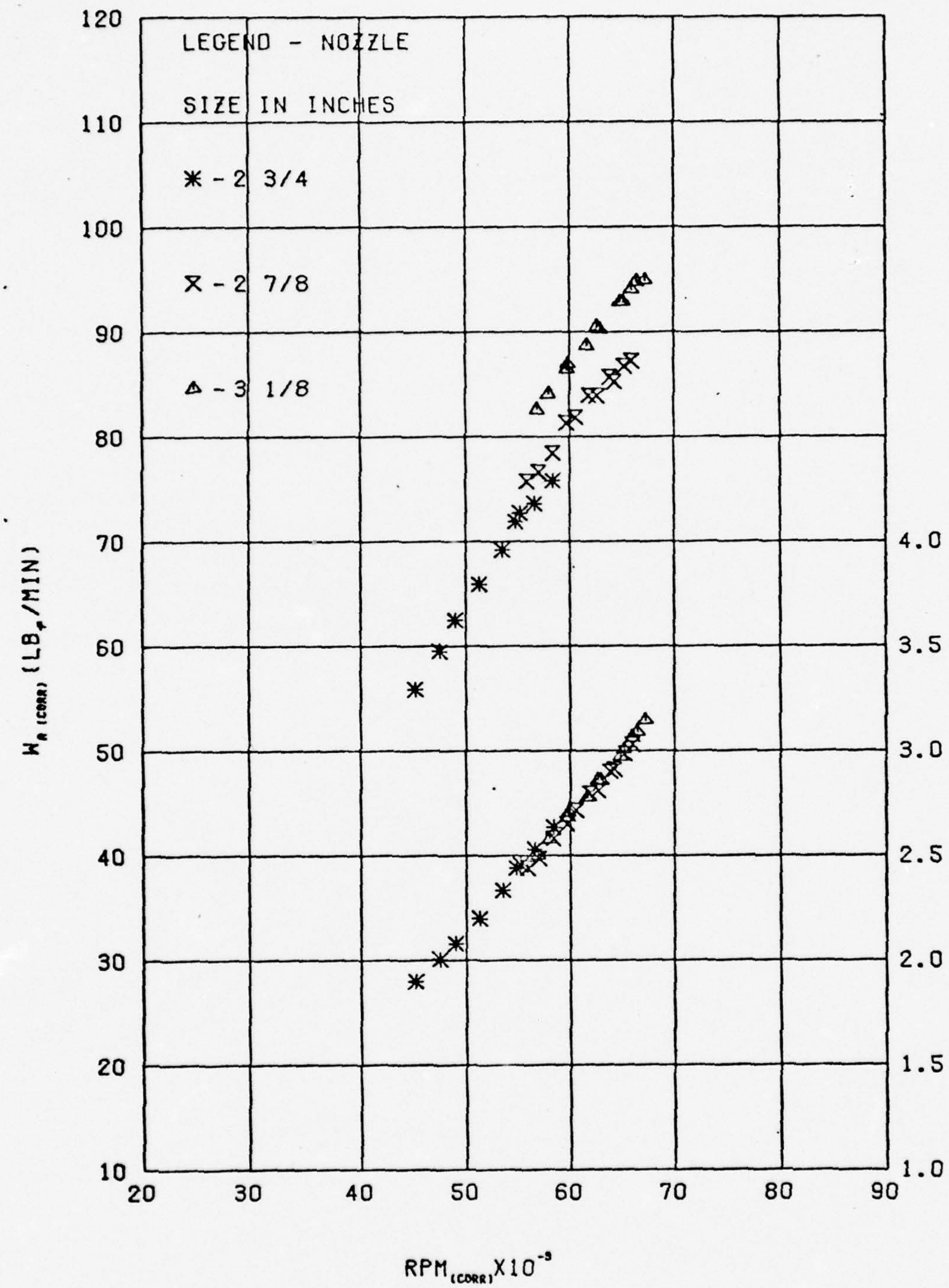


Fig. 21 RPM Crossplot for 1.32 A/R Housing

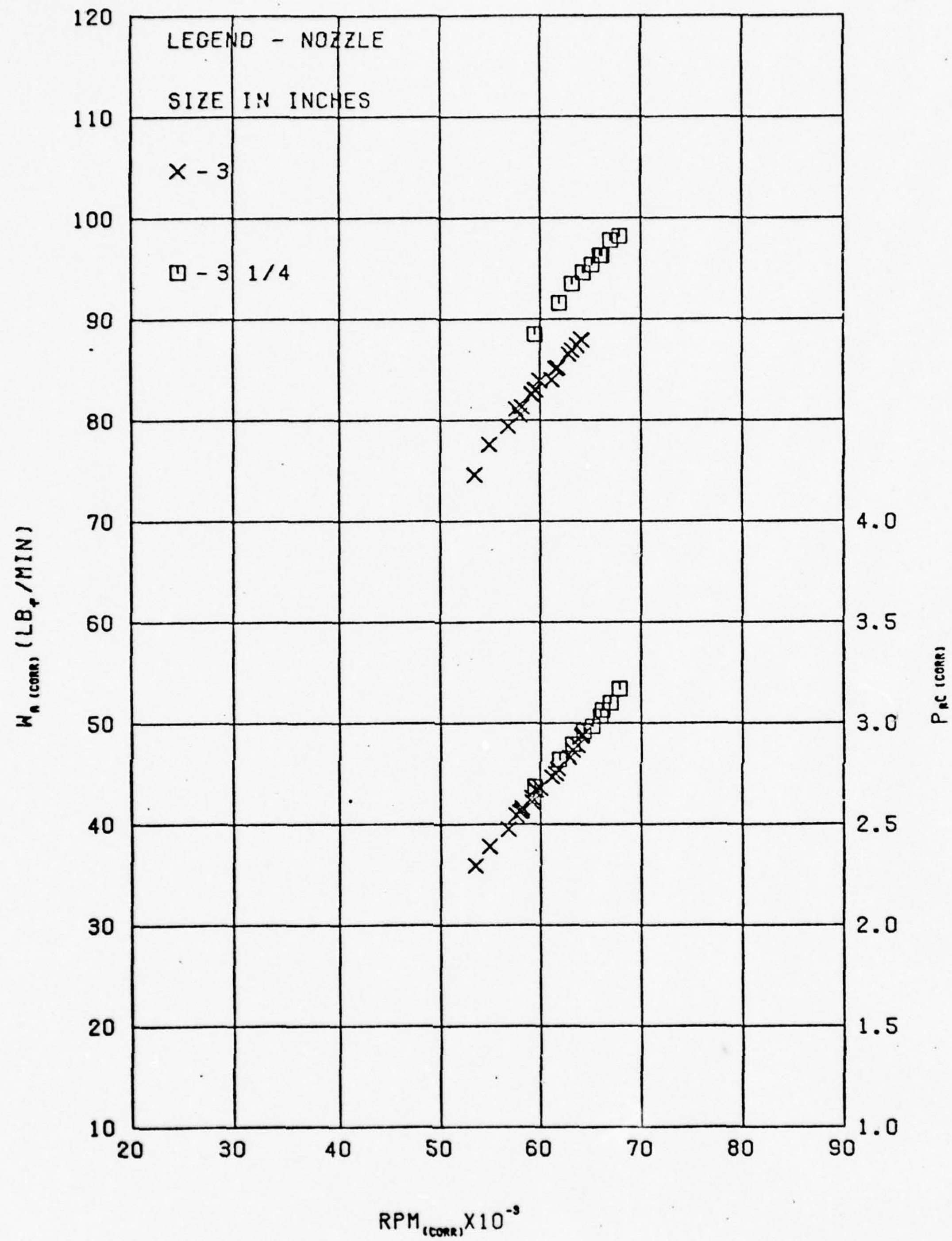


Fig. 22 RPM Crossplot for 1.32 A/R Housing

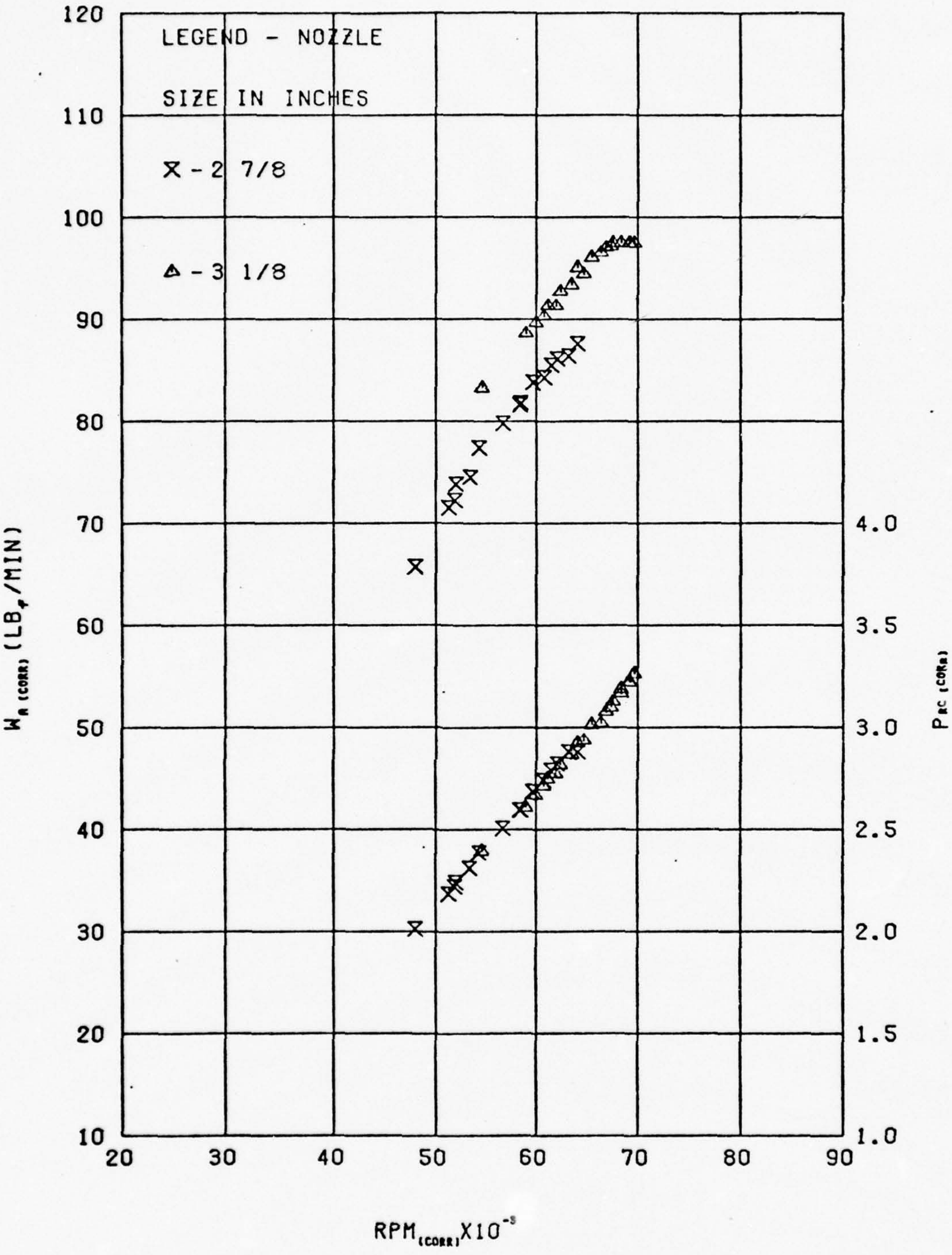


Fig. 23 RPM Crossplot for 1.5 A/R Housing

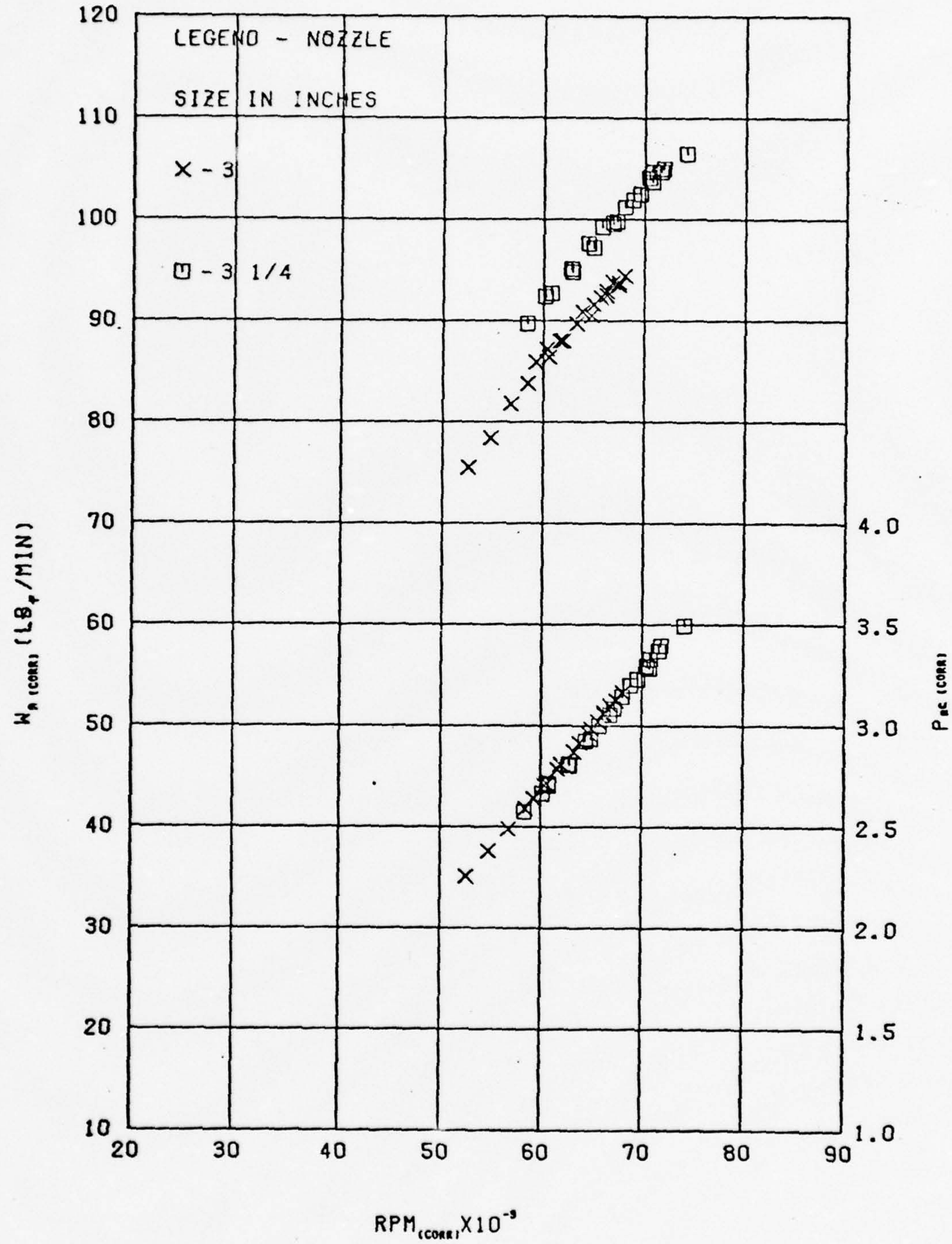


Fig. 24 RPM Crossplot for 1.5 A/R Housing

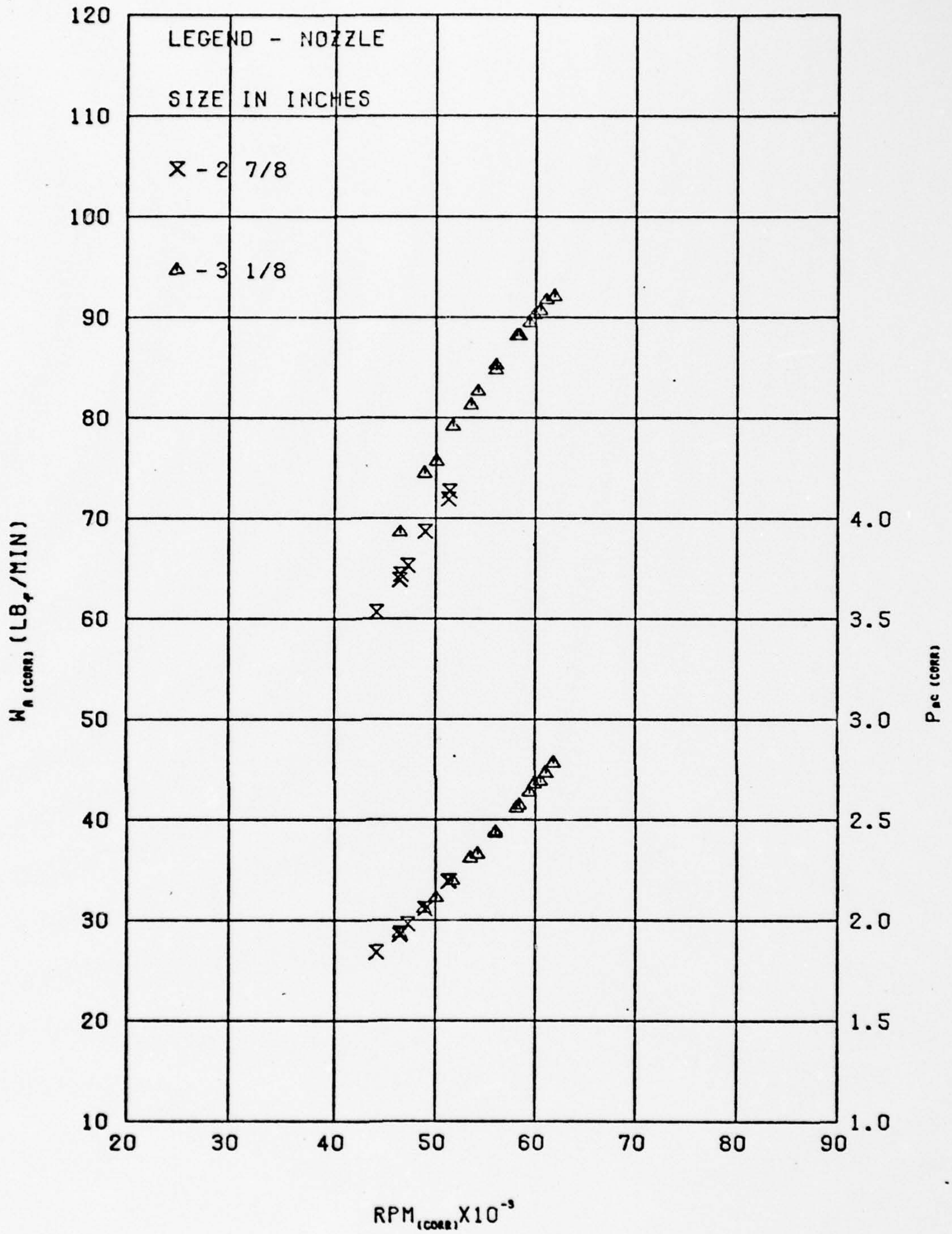


Fig. 25 RPM Crossplot for 1.7 A/R Housing

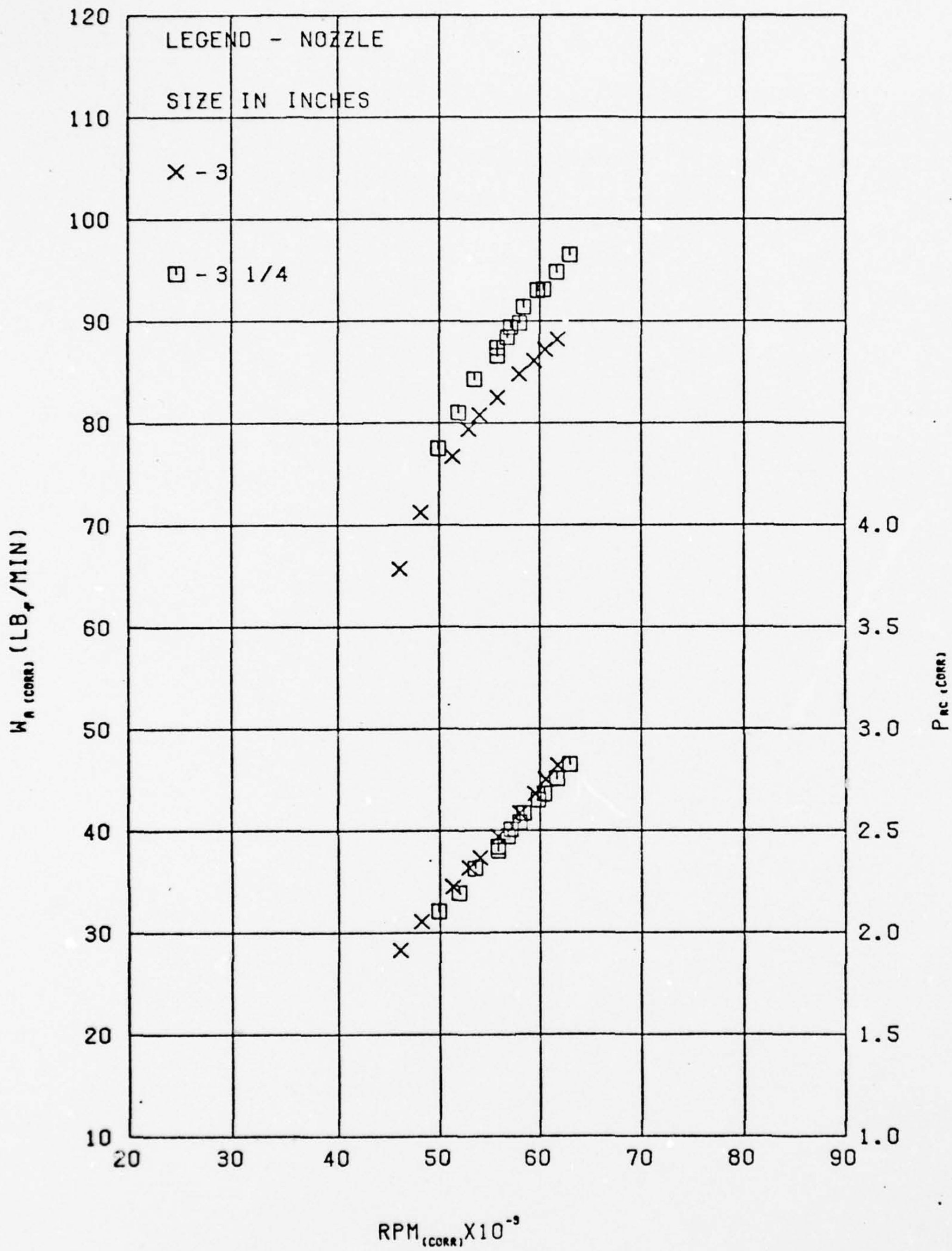


Fig. 26 RPM Crossplot for 1.7 A/R Housing

Appendix C

Test Data

This appendix contains all the data recorded and presented in the results section. They are listed sequentially by test run number.

Designation

The I designation denotes a fully instrumented test run. The dash number refers to the number in a series of runs with the same nozzle. For example, I-14-1 is the first run of a series with an A/R of 1.32 and a 3 inch nozzle; I-14-2 is the second run of the series. The same series may also be run on two different days. A run consists of at least a start, sustained idle with at least one steady-state data point, and a shutdown. A slash between two numbers indicates a combined run with no shutdown between them, usually an idle test and profile run. A letter following the dash number indicates a repeat of the same profile.

Coding

Data have been read from the strip chart to the nearest hundredth of an inch and were coded without the decimal point for ease of data handling and storage on card decks in ten columns of three digit numbers each. All data is then read into whatever program is desired and the specific variables required in a computation are

simply called by column number. Thus column 1 and 10 would be called to plot P_{rc} and W_a . This data recording and storage scheme is very convenient for manipulating the data, especially since there are a number of other possible combinations available for analysis, such as fuel flow versus RPM, P_{rc} versus thrust, P_{rc} versus SFC, etc. See appendix A for performance programs.

Invalid Data

Some of the data was obviously erroneous due to sensor or recording equipment malfunction and was excluded from the data or was included in the data but excluded from the results. In particular, the portion of the Potter Model THM-005 correction curve shown in Fig. 27 is non-linear below approximately 40 Hz . Therefore, values of fuel flow below approximately 2 inches on the strip recorder (corresponding to 40 Hz) were not plotted in Figs. 6 through 17. This accounts for the behavior of some of the SFC curves which either slope too steeply or fail to increase at low flow rates.

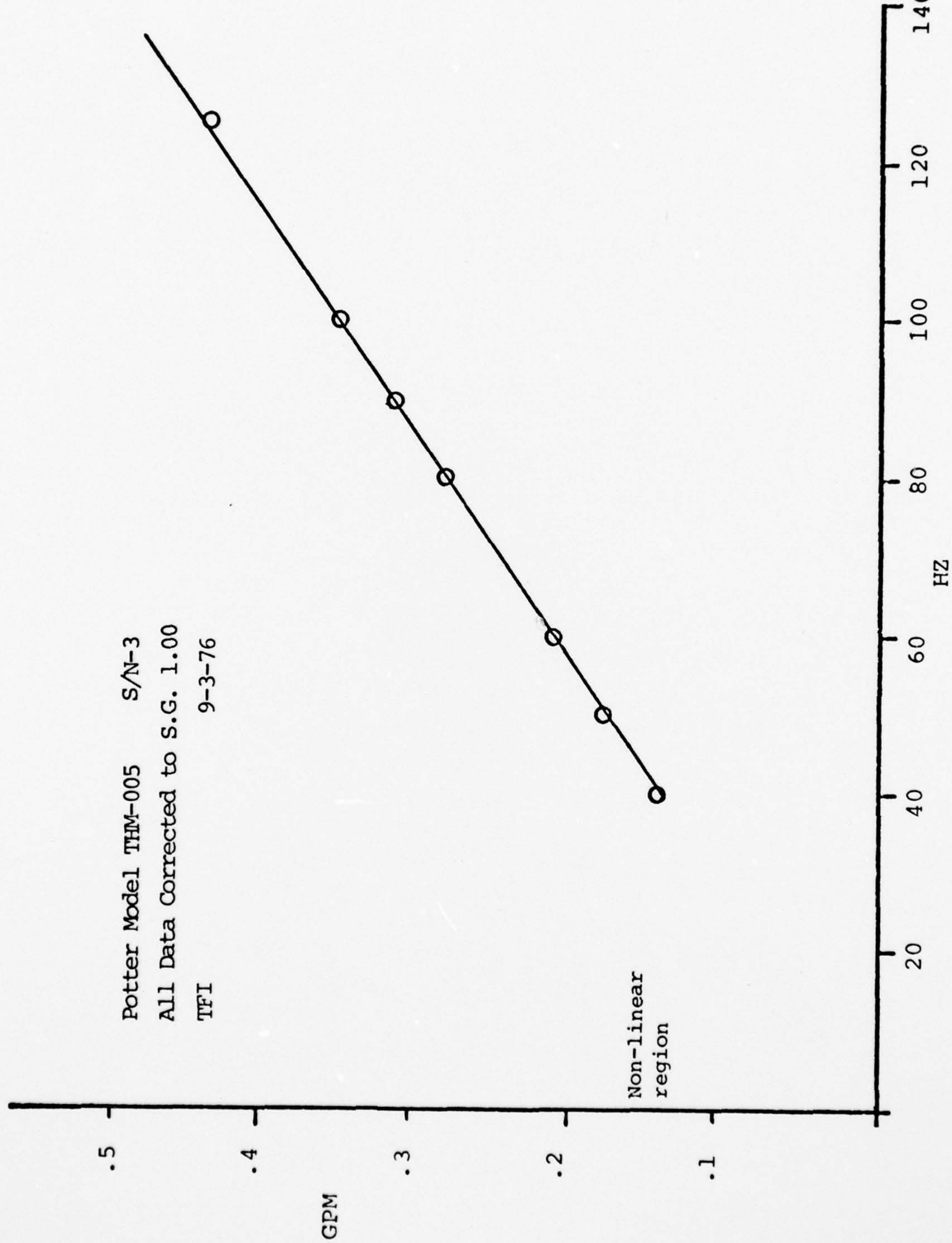


Fig. 27 Potter Model THM-005 Fuel Flow Correction Curve

TEST RUN I- 7

DATE: 3 OCT '75
AR: 1.7
NOZZLE: 2 7/8 IN
TEMP: 57 DEG F
PRESS: 14.41 PSI
TIME: 350 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	123	202	48	220	362	313	30	170	305	258
2	160	252	68	252	420	350	140	225	338	338
3	180	305	80	275	435	364	216	270	358	391
4	195	330	90	290	452	376	258	236	370	416
5	193	329	90	290	450	380	250	235	369	410
6	204	344	95	299	463	388	295	310	376	428
7	218	370	106	312	480	400	325	335	388	440
8	195	330	90	294	450	381	257	299	369	415
9	176	294	78	276	422	365	210	255	352	378
10	155	253	65	260	395	354	172	230	335	332
11	115	189	43	214	378	324	50	150	295	240

TEST RUN I- 8

DATE: 3 OCT 75
AR: 1.7
NOZZLE: 2 3/4 IN
TEMP: 57 DEG F
PRESS: 14.41 PSI
TIME: 177 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	104	159	47	185	411	320	5	145	280	30
2	135	225	68	221	470	354	150	200	316	29
3	100	151	45	195	380	338	5	150	278	23

TEST RUN I- 9

DATE: 3 OCT 75
AR: 1.7
NOZZLE: 2 5/8 IN
TEMP: 57 DEG F
PRESS: 14.41 PSI
TIME: 77 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	86	140	45	170	500	346	5	125	260	21

TEST RUN I- 10-2

DATE: 3 OCT 76
AR: 1.7
NOZZLE: 3 IN
TEMP: 74 DEG F
PRESS: 14.30 PSI
TIME: 575 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	151	250	52	241	332	256	280	200	416	345
2	175	295	62	266	349	315	350	240	442	401
3	189	318	71	280	360	327	375	255	456	430
4	195	331	75	291	375	335	390	279	465	445
5	210	356	84	304	381	344	410	306	480	464
6	227	387	93	325	412	365	449	335	499	490
7	240	411	101	340	423	380	474	361	511	505
8	250	429	110	353	454	391	500	380	521	518
9	260	448	116	368	493	405	525	338	531	530
10	131	220	43	230	340	300	241	182	398	294

TEST RUN I- 11-2

DATE: 3 OCT 75
AR: 1.7
NOZZLE: 3 1/8 IN
TEMP: 74 DEG F
PRESS: 14.30 PSI
TIME: 507 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	151	245	37	245	350	286	256	192	420	378
2	171	234	46	269	363	300	300	222	444	427
3	190	315	54	287	382	310	349	250	465	465
4	205	340	60	306	395	325	382	275	480	495
5	223	372	70	322	420	340	419	307	498	530
6	234	391	75	338	439	350	437	324	509	545
7	242	405	79	345	451	358	455	339	518	560
8	248	418	81	352	465	365	458	348	523	573
9	255	429	85	360	480	370	480	350	530	578
10	240	401	78	346	461	350	442	338	513	555
11	225	374	70	331	440	349	419	315	500	530
12	206	340	61	310	412	331	380	283	480	490
13	187	305	52	290	395	319	331	250	459	450
14	159	258	40	261	371	311	258	208	430	390
15	133	214	30	240	351	291	221	171	400	321

TEST RUN I- 12-1/2

DATE: 3 OCT 76
AR: 1.7
NOZZLE: 3 1/4 IN
TEMP: 74 DEG F
PRESS: 14.30 PSI
TIME: 400 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	158	252	26	260	371	270	240	185	430	409
2	188	303	36	289	391	289	285	225	461	484
3	203	334	41	306	403	301	337	250	480	521
4	215	354	47	318	419	310	377	258	491	545
5	227	375	50	331	435	321	400	285	502	569
6	240	399	56	349	454	332	422	305	519	590
7	251	419	60	360	464	343	448	324	530	612
8	261	438	63	375	481	356	470	340	541	634
9	236	389	53	349	450	333	414	304	514	589
10	220	350	48	331	430	321	390	281	499	550
11	210	342	44	320	421	313	350	257	489	533
12	200	329	40	313	412	310	324	255	480	511
13	171	278	31	279	390	230	250	212	447	447

TEST RUN I- 13-1/2

DATE: 3 OCT 76
AR: 1.7
NOZZLE: 2 7/8 IN
TEMP: 74 DEG F
PRESS: 14.30 PSI
TIME: 235 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	134	217	50	241	420	317	239	183	401	283
2	151	249	60	252	440	332	278	212	421	322
3	171	284	71	271	467	350	340	250	441	360
4	140	225	52	241	411	330	250	200	407	291
5	170	280	70	270	481	360	332	245	440	352
6	132	215	50	240	405	329	225	138	400	278
7	120	190	41	221	390	320	201	167	380	251

TEST RUN I- 14-1

DATE: 3 OCT 76
AR: 1.32
NOZZLE: 3 IN
TEMP: 74 DEG F
PRESS: 14.35 PSI
TIME: 125 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	222	389	60	330	350	290	235	247	495	450

TEST RUN I- 14-2

DATE: 3 OCT 76
AR: 1.32
NOZZLE: 3 IN
TEMP: 74 DEG F
PRESS: 14.30 PSI
TIME: 106 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	233	410	67	346	361	307	328	270	509	454

TEST RUN I- 14-3

DATE: 3 OCT 76
AR: 1.32
NOZZLE: 3 IN
TEMP: 73 DEG F
PRESS: 14.30 PSI
TIME: 330 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	239	415	67	350	370	302	349	270	511	469
2	254	444	76	371	392	325	375	299	530	495
3	262	460	80	381	415	335	391	313	540	510
4	277	482	88	397	0	350	413	336	550	528
5	267	463	82	389	0	341	394	320	542	515
6	226	391	64	346	0	313	300	265	500	450

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PARAMETRIC PERFORMANCE EVALUATION OF A JET ENGINE DERIVED FROM --ETC(U)
MAR 77 R B BROWN

UNCLASSIFIED AFIT/GAE/AE/76D-2 NL

2 OF 2
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TEST RUN I- 14-4

DATE: 3 OCT 76
AR: 1.32
NOZZLE: 3 IN
TEMP: 73 DEG F
PRESS: 14.30 PSI
TIME: 357 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	223	389	60	330	360	295	290	252	498	442
2	239	412	68	351	391	311	338	275	512	469
3	248	431	72	370	407	324	365	292	525	481
4	260	455	80	380	425	334	387	310	438	504
5	270	474	84	391	470	345	404	328	546	520
6	278	490	87	400	0	351	414	338	551	527
7	250	431	80	375	0	350	405	322	529	494
8	240	411	76	360	0	341	380	305	515	480
9	230	397	71	350	0	335	363	290	508	465
10	224	381	70	342	0	331	354	280	500	450
11	211	360	61	330	0	322	322	251	488	430
12	199	337	57	316	0	316	294	243	472	410
13	185	311	50	300	0	307	260	222	460	379

TEST RUN I- 15-1

DATE: 3 OCT 75
AR: 1.32
NOZZLE: 2 7/8 IN
TEMP: 73 DEG F
PRESS: 14.30 PSI
TIME: 230 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	206	354	66	315	570	313	240	239	479	390
2	226	334	77	335	510	320	335	270	500	419
3	212	370	71	328	571	320	279	255	488	400

TEST RUN I- 15-1/2

DATE: 4 OCT 76
AR: 1.32
NOZZLE: 2 7/8 IN
TEMP: 74 DEG F
PRESS: 14.30 PSI
TIME: 300 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	236	425	94	327	550	333	349	235	511	450
2	257	462	106	349	587	355	395	326	530	480
3	272	490	115	366	619	372	430	350	547	500
4	284	511	122	379	642	388	454	370	559	512
5	290	523	128	392	0	401	442	333	565	518
6	273	492	118	379	0	386	397	358	550	495
7	259	457	110	361	0	372	365	339	537	480
8	245	438	100	341	0	358	317	313	519	456

TEST RUN I- 18-2

DATE: 5 OCT 75
AR: 1.32
NOZZLE: 2 3/4 IN
TEMP: 74 DEG F
PRESS: 14.25 PSI
TIME: 300 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	205	357	91	282	435	339	200	257	470	351
2	233	420	113	320	470	378	300	318	500	390
3	218	389	102	310	450	359	227	282	485	358
4	207	358	95	298	435	350	189	256	473	359
5	190	340	85	284	419	347	159	242	459	325
6	171	305	74	268	400	339	111	217	440	295
7	154	277	64	252	380	322	70	194	421	255
8	143	255	58	240	363	312	24	175	408	240
9	128	228	50	229	350	305	0	151	389	212

TEST RUN I- 19-1/2

DATE: 5 OCT 76
AR: 1.32
NOZZLE: 3 1/8 IN
TEMP: 74 DEG F
PRESS: 14.25 PSI
TIME: 337 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	214	378	48	299	351	275	118	228	488	453
2	243	429	59	327	385	296	155	266	513	513
3	265	465	67	349	403	311	207	297	537	556
4	286	504	75	370	443	329	231	328	558	585
5	298	527	80	388	465	340	328	348	569	610
6	306	543	85	400	497	350	355	360	576	612
7	294	520	80	389	465	343	322	346	565	600
8	281	497	74	378	435	335	270	329	555	585
9	265	455	67	360	411	322	223	305	539	553
10	253	445	62	348	399	315	195	290	528	534
11	240	420	58	332	385	305	162	270	512	507
12	225	392	51	320	363	296	123	249	497	480

TEST RUN I- 20-1/2

DATE: 5 OCT 75
AR: 1.32
NOZZLE: 3 1/4 IN
TEMP: 74 DEG F
PRESS: 14.25 PSI
TIME: 250 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	240	418	41	322	372	271	180	240	511	532
2	259	452	46	342	384	284	221	255	532	570
3	270	472	50	356	404	292	250	280	543	593
4	283	495	54	375	420	305	298	301	560	518
5	294	518	58	387	435	313	330	319	568	530
6	309	544	62	400	467	324	378	338	582	555
7	299	528	60	400	472	323	350	328	575	550
8	290	509	58	390	455	319	319	315	566	530
9	279	489	52	372	445	309	259	300	552	508

TEST RUN I- 21-1

DATE: 6 OCT 76
AR: 1.5
NOZZLE: 2 7/8 IN
TEMP: 55 DEG F
PRESS: 14.25 PSI
TIME: 200 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	170	290	68	241	357	2?9	0	220	430	311

TEST RUN I- 21-2

DATE: 6 OCT 75
AR: 1.5
NOZZLE: 2 7/8 IN
TEMP: 55 DEG F
PRESS: 14.25 PSI
TIME: 450 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	120	203	41	193	328	2[illegible]9	0	142	372	213
2	147	251	54	218	350	231	0	131	405	266
3	166	285	64	232	359	291	0	211	427	300
4	182	312	73	251	373	306	0	238	447	332
5	204	350	86	269	383	320	0	270	465	371
6	215	358	93	279	393	330	0	232	476	390
7	231	395	104	294	415	346	0	320	492	405
8	241	414	110	309	430	350	0	340	503	430
9	269	452	130	332	459	388	0	389	530	354
10	295	511	150	361	500	420	0	440	555	374
11	253	435	120	333	451	339	0	372	519	339
12	240	410	111	316	433	378	0	348	503	325
13	228	339	103	303	419	355	0	323	491	311
14	212	360	93	288	401	351	0	299	475	295
15	200	339	85	272	382	335	0	272	461	272
16	171	292	70	250	363	320	0	230	435	240
17	150	255	58	231	351	304	0	196	411	214

TEST RUN I- 22-1/2

DATE: 5 OCT 76
AR: 1.5
NOZZLE: 3 IN
TEMP: 55 DEG F
PRESS: 14.25 PSI
TIME: 450 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	162	279	51	230	340	274	0	137	426	245
2	189	320	62	253	352	290	0	235	452	283
3	208	351	71	270	370	300	0	354	470	310
4	224	380	81	285	381	313	0	232	488	330
5	231	392	85	296	389	321	0	305	495	340
6	247	420	94	311	403	335	0	331	511	364
7	255	433	99	321	411	344	0	345	520	370
8	263	450	103	329	421	354	0	350	529	380
9	269	451	108	338	430	350	0	371	533	384
10	281	431	115	348	444	372	0	391	544	398
11	289	495	120	358	459	380	0	406	552	399
12	310	535	135	381	503	409	0	449	573	412
13	293	504	123	365	461	393	0	420	557	400
14	283	486	118	358	450	385	0	404	549	392
15	264	450	106	340	429	370	0	370	530	368
16	256	434	100	330	412	361	0	357	521	359
17	243	412	93	315	402	349	0	334	508	345
18	222	377	82	299	382	332	0	299	488	321
19	208	348	73	281	368	320	0	271	470	301
20	210	356	77	279	375	319	0	278	475	306

TEST RUN I- 23-1/2

DATE: 6 OCT 76
AR: 1.5
NOZZLE: 3 1/8 IN
TEMP: 55 DEG F
PRESS: 14.25 PSI
TIME: 525 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	230	388	66	296	370	294	0	281	498	360
2	240	405	70	305	378	305	0	299	508	378
3	255	430	76	319	289	313	0	320	521	391
4	264	449	80	330	400	326	0	337	531	408
5	275	466	85	339	412	332	0	351	540	420
6	237	395	70	303	372	310	0	303	504	370
7	261	439	81	323	397	339	0	257	529	398
8	278	469	89	341	417	341	0	351	542	418
9	290	493	94	353	431	353	0	380	556	426
10	302	512	100	370	445	365	0	400	568	435
11	307	522	105	379	452	373	0	410	572	446
12	321	550	111	392	469	387	0	438	585	460
13	341	589	124	412	495	409	0	471	606	481
14	316	539	110	392	462	385	0	430	581	558
15	304	515	102	380	443	375	0	410	570	435
16	290	490	95	365	431	365	0	337	559	420
17	272	450	87	350	411	349	0	350	540	404
18	253	425	79	330	391	334	0	329	521	382
19	225	373	65	301	365	313	0	281	491	343
20	211	350	60	284	355	302	0	250	478	329

TEST RUN I- 24-1/2

DATE: 5 OCT 75
AR: 1.5
NOZZLE: 3 1/4 IN
TEMP: 55 DEG F
PRESS: 14.25 PSI
TIME: 530 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	263	441	61	331	380	305	0	310	531	415
2	277	454	65	341	390	314	0	330	543	440
3	287	483	70	355	402	324	0	345	556	452
4	300	509	75	366	419	334	0	366	568	454
5	331	564	89	401	450	365	0	410	596	498
6	351	602	96	431	495	390	0	450	615	510
7	336	575	90	416	470	379	0	428	605	508
8	323	550	85	402	445	357	0	409	592	496
9	310	521	80	390	430	355	0	339	578	475
10	287	480	71	362	393	335	0	353	556	450
11	266	444	62	345	382	320	0	322	537	425
12	245	408	55	321	365	305	0	310	515	400
13	264	441	62	332	381	316	0	319	534	420

TEST RUN I- 25-1/2

DATE: 5 OCT 75
AR: 1.5
NOZZLE: 3 1/4 IN
TEMP: 55 DEG F
PRESS: 14.25 PSI
TIME: 402 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	181	315	96	249	405	316	0	258	441	210
2	203	355	111	268	433	339	0	297	463	231
3	217	380	122	279	448	355	0	321	476	241
4	233	411	137	294	469	380	0	358	491	256
5	250	440	149	308	494	395	0	384	509	269
6	224	389	128	290	452	371	0	337	482	244
7	203	352	111	273	429	359	0	300	463	223
8	192	333	103	267	417	341	0	280	453	215
9	175	305	92	250	398	323	0	251	436	200
10	161	279	81	240	383	313	0	229	420	185
11	147	253	72	225	372	300	0	205	405	169
12	132	228	63	209	352	286	0	131	387	152
13	117	200	53	195	340	273	0	157	369	132
14	102	173	46	182	323	250	0	133	346	117

TEST RUN I- 25-1/2A

DATE: 5 OCT 75
AR: 1.5
NOZZLE: 3 1/4 IN
TEMP: 55 DEG F
PRESS: 14.25 PSI
TIME: 244 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	82	139	33	158	332	2[illegible]5	0	99	318	99
2	122	211	55	192	370	311	0	150	379	151
3	140	240	66	204	382	320	0	183	395	171
4	160	277	80	223	400	332	0	218	420	197
5	181	315	96	242	419	348	0	252	442	220
6	198	340	105	259	433	362	0	279	458	233
7	239	413	138	298	480	410	0	357	497	271

TEST RUN I- 26-1/2

DATE: 7 OCT 75
AR: 1.5
NOZZLE: 2 7/8 IN
TEMP: 50 DEG F
PRESS: 14.35 PSI
TIME: 530 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	199	340	80	271	380	300	258	255	455	410
2	178	315	70	259	360	295	250	234	436	372
3	229	395	101	312	430	345	355	323	490	457
4	242	420	110	330	440	358	398	348	500	480
5	257	447	120	350	457	375	431	374	515	500
6	270	459	130	365	473	390	454	394	529	511
7	270	489	137	375	485	401	485	415	536	525
8	261	459	125	360	460	387	450	339	520	507
9	250	431	118	346	449	375	418	357	509	486
10	229	394	103	326	420	459	355	330	489	455
11	216	372	95	315	409	349	340	309	475	435
12	188	320	78	281	371	325	234	258	448	380
13	170	292	69	264	360	314	250	230	430	350
14	145	248	54	238	333	299	218	189	403	295
15	175	300	70	263	360	313	256	235	435	356

TEST RUN I- 27-1/2

DATE: 7 OCT 75
AR: 1.5
NOZZLE: 3 IN
TEMP: 50 DEG F
PRESS: 14.35 PSI
TIME: 400 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	235	405	88	323	405	333	350	318	497	505
2	245	420	92	332	414	332	391	330	506	520
3	256	440	98	348	425	341	430	351	517	530
4	268	450	105	364	440	355	450	370	530	550
5	275	475	110	371	445	354	476	383	535	565
6	285	493	116	382	461	371	495	400	544	574
7	290	504	120	392	465	380	510	412	550	582
8	296	512	122	400	479	339	522	422	555	590
9	301	524	128	402	478	390	532	431	560	502
10	305	530	130	414	489	400	545	444	565	502
11	311	540	133	420	395	410	559	457	570	610
12	305	530	130	418	490	405	540	445	565	598
13	295	510	125	401	478	397	520	428	555	585
14	281	486	117	392	465	389	495	409	543	560
15	260	442	102	367	435	370	437	359	520	530
16	246	420	95	350	420	355	401	348	508	511
17	228	388	85	339	404	345	352	315	491	480
18	214	352	78	315	395	331	335	294	477	457
19	198	330	70	294	370	320	284	250	460	420
20	180	310	60	271	349	305	255	237	442	390

TEST RUN I- 28-1/2

DATE: 7 OCT 75
AR: 1.5
NOZZLE: 3 1/8 IN
TEMP: 50 DEG F
PRESS: 14.35 PSI
TIME: 600 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	200	338	51	276	351	265	302	235	458	474
2	231	395	67	322	370	293	359	288	494	537
3	251	429	75	344	385	319	395	315	512	570
4	261	449	80	360	395	320	414	334	522	598
5	276	471	87	373	408	331	440	355	536	618
6	289	495	93	389	420	343	459	378	548	631
7	298	512	99	405	435	355	486	394	559	644
8	305	528	101	415	443	366	505	410	565	650
9	314	540	107	426	458	373	524	424	572	650
10	319	550	110	434	481	381	539	433	578	650
11	325	560	112	441	478	389	550	445	582	650
12	319	550	110	434	468	383	539	437	579	650
13	311	538	108	430	460	384	525	429	572	650
14	301	519	100	419	450	375	500	410	563	645
15	290	499	97	405	430	364	478	396	555	637
16	278	471	90	390	413	365	447	370	541	610
17	268	455	84	375	401	344	424	355	531	596
18	254	431	78	360	390	333	398	334	519	570
19	246	415	74	349	380	325	278	318	509	558
20	239	436	71	339	375	320	353	306	502	549

TEST RUN I- 29-1/2

DATE: 7 OCT 76
AR: 1.5
NOZZLE: 3 1/4 IN
TEMP: 50 DEG F
PRESS: 14.35 PSI
TIME: 850 SEC

DATA POINT	P3	P4	P5	T3	T4	T5	F/F	FN	RPM	WA
1	246	415	55	344	366	292	358	288	510	588
2	260	440	60	361	380	308	397	310	526	619
3	276	470	66	379	397	319	421	335	540	651
4	287	488	70	398	412	330	448	350	551	673
5	299	510	74	409	421	339	470	359	563	681
6	308	525	78	419	429	346	485	380	570	701
7	320	549	82	440	447	360	511	401	582	719
8	329	563	87	446	451	366	523	417	590	741
9	334	574	90	453	458	372	538	426	592	750
10	344	591	93	472	478	386	558	440	601	754
11	358	620	100	491	503	408	607	473	620	775
12	340	583	93	468	471	390	559	444	600	750
13	328	562	88	451	460	380	535	427	592	735
14	316	540	83	437	447	370	506	409	577	710
15	295	500	75	413	425	353	458	376	560	678
16	278	469	67	394	410	340	426	349	544	646
17	259	434	60	379	390	329	394	320	527	615
18	245	411	55	355	371	312	363	299	510	588
19	226	378	50	331	356	299	330	272	490	550
20	239	404	54	338	369	304	359	289	505	584

Appendix D

Detailed Calculations and Data Reduction

This appendix contains the detailed tables and data reduction formulas to convert the raw data to the correct parameter with the appropriate unit, and to correct the values of the parameters to a standard day. It also contains an estimate of experimental accuracy by comparison of the theoretically derived thrust to that measured experimentally.

Table 1

Strip Chart Inch Equivalent Values

Values correspond to one inch as measured on the strip recorder.

P_3	-	10 PSI
P_4	-	5 PSI
P_5	-	5 PSI
T_3	-	100 ^oF
T_4	-	400 ^oF
T_5	-	400 ^oF
F/F	-	20 HZ
FN	-	20 lb_f
RPM	-	12000
$\dot{m}$	-	2 in H_2O

The readins for F/F and m require additional conversion to obtain the correct units as shown in the following table:

Table 2

Fuel Flow and Airflow Conversion Constants

F/F (lb/hr)	=	(325/180) (.75) (Hz)
W_a	= $\dot{m}$ (lb_m/min) =	(111.24) $\sqrt{PINF/TINF}$

In the above table, (325/180) is the slope of the Potter correction curve, .75 is specific gravity, and Hz is the number obtained in Table 1. The number 111.25 is a constant as derived by Fisher (Ref 1.). (See the computer program listings for additional comments concerning conversions.)

Table 3

Additional Formulas

$$F_{n\,(corr)} = F_{n\,(IND)} / \delta$$

$$RPM_{(corr)} = RPM_{(IND)} / \sqrt{\theta}$$

$$W_{f\,(corr)} = \frac{W_{f\,(IND)}}{\delta \sqrt{\theta}}$$

$$SFC_{(CORR)} = \frac{W_{f\,(CORR)}}{F_{n\,(CORR)}}$$

$$W_{a\,(CORR)} = \frac{W_{a\,(IND)} \sqrt{\theta}}{\delta}$$

$$\theta = T/T_o$$

$$\delta = P/P_o$$

Estimate of Experimental Accuracy

Thrust equation:

$$F_n / W_a = (1+f)\sqrt{2\, c_p\, T_{os}\, \eta_n \left[1 - 1/P_{rn}\right]\frac{\gamma-1}{\gamma}}$$

where it is assumed that

$$f = .02$$
$$\eta_n = 1.0$$

For A/R 1.5 and 3 1/4 nozzle, corrected thrust is 97 lb_f.

From thrust equation with

$$c_p = .2855 \ \text{BTU/lb °F}$$
$$T_{os} = 2000 \ \text{°R}$$
$$\gamma = 1.316$$

Predicted theoretical thrust is 92 lb_f.

$\approx$ 5% accuracy

Vita

Richard B. Brown was born March 10, 1940 in Trenton, New Jersey. He received his B.S. degree in Aeronautical Engineering at St. Louis University and subsequently was commissioned in the U.S. Air Force through the OTS program. He completed pilot training in 1965 and served as an F-4 aircraft commander and T-39 flight examiner. He was later assigned to the A-70 Program Office as a sybsystem manager and served a special tour as a White House social aid from 1972 to 1974. He subsequently entered AFIT to obtain his M.S. degree.

This thesis was typed by: Mrs. Bonnie L. Templeton

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19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

TURBOJET ENGINE	TURBOCHARGER
LOW THRUST TURBOJET	TURBOCHARGER ENGINE
LOW COST TURBOJET	RPV ENGINE
EXPENDABLE TURBOJET	JET ENGINE

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Previous conceptual studies have shown that it is feasible to construct a low-thrust, jet engine, based on a production turbocharger at relatively low cost. A parametric evaluation was performed on a turbojet engine derived from an AiResearch 1.5 lb_m/sec airflow turbocharger unit to determine its static performance characteristics and the maximum attainable thrust without augmentation or major component modification. The

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performance of various turbine housing/nozzle combinations was measured in steady state operation using a much improved instrumentation system, together with various system improvements. Parameters were measured on a common time base and plotted to depict the total performance of the unit over its usable range. Maximum thrust obtained was 97 lb_f, exceeding the initially predicted theoretical value of 67 lb_f by 45%.

Data was reduced to coded 3 digit numbers for programming and plotting using the CDC 6600 computer. The results were machine plots depicting the performance characteristics of the unaugmented engine for use in further studies including augmentation. In addition, computer performance programs for coded raw data were written for future data reduction and analysis.